Edge Effects on Small Skinks: Their Prey, Predators and Competitors in Peri-urban Remnants in North-western Sydney.

By,

Lynette Patricia Anderson

B. App. Sc., University of Western Sydney.

B. Sc. (Hons), University of Western Sydney.


2007.
This thesis is dedicated to the memory of my father, Thomas Richard Anderson, who passed from this life before seeing me wear the silly hat. I thank him for his support and love.
Acknowledgements

The term ‘no man is an island’ is true when one undertakes a project of this magnitude. I would like to thank those people who took the time to help me along the way.

My supervisor Shelley Burgin for her guidance, support and patience, thank you.

For all their technical and moral support, I would like to thank Jennie Nelson and Susan Coombe.

Al Glen, Simon Cook, Tony Saunders and Chris Schneider for help with my methods.

To my colleagues, Chris Schell and Adrian Renshaw, thanks for the help with the stats, the intelligent discussions, laughs and sympathy.

My greatest thanks go to my family, who once again gave me support, love and money. Special thanks to my brother, Kevin (who did a lot of the leg work in the field, and kept me from stepping on snakes), my sister Teresa and brother-in-law Gary (for keeping a roof over my head and food in my stomach), my nephew Andrew (whose hugs and kisses gave me the strength to carry on) and finally to my mum Patricia (whose love is unending).

To all of you thank you from the bottom of my heart.
Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in whole or in part, for a degree at this or any other institution.

Lynette Patricia Anderson.
Table of Contents.

Dedication .............................................................................................................................................. i
Acknowledgements................................................................................................................................ ii
Statement of Authentication............................................................................................................... ................ iii
Table of Contents. ............................................................................................................................... iv
Table of Tables .................................................................................................................................. viii
Table of Figures............................................................................................................... .................... xi
Table of Plates .................................................................................................................................. xvii
Abstract............................................................................................................................................ xviii

Chapter 1. General Introduction. ...................................................................................................... 1
  1.1. INTRODUCTION. .......................................................................................................................... 1
  1.2. EDGE EFFECTS............................................................................................................................. 3
    1.2.1 Abiotic impacts on flora and fauna...................................................................................... 3
      1.2.1.1 Microclimate........................................................................................................................ 3
      1.2.1.2. Water Regimes.................................................................................................................. 7
      1.2.1.3. Barrier Effects.................................................................................................................... 8
      1.2.1.4. Age.................................................................................................................................... 9
    1.1.2. BIOTIC EDGE EFFECTS........................................................................................................ 10
      1.1.2.1. Abundance and Diversity............................................................................................... ........... 10
      1.1.2.2 Predation .............................................................................................................. ...................... 13
    1.1.3 Anthropogenic Impacts.................................................................................................... .. 15

Chapter 2. Site Description .............................................................................................................. 24
  2.1. STUDY AREA................................................................................................................................ 24
    2.1.2. Cumberland Plain Bushland............................................................................................. 24
    2.1.2. Study Site - Hawkesbury. .................................................................................................. 26
    2.1.3. Remnant description and selection. .................................................................................. 27

Chapter 3. Edge Effects on Community Diversity. ........................................................................ 33
  3.1. INTRODUCTION. .......................................................................................................................... 33
  3.2. METHODS.................................................................................................................................. 36
    3.2.1. Skink Sampling ...................................................................................................................... 36
Chapter 5: Skink Abundance and Diversity

5.3.1. Skink abundance and diversity ................................................................. 97
5.3.2. Lamprophis general diet ......................................................................... 97
5.3.3. Overall abundance and diversity of prey – size and order ..................... 99
5.3.4. Common dietary items - abundance, diversity and size .......................... 105
5.3.5. Abundance of preferred prey – size and order ....................................... 110
5.4. DISCUSSION ......................................................................................... 117

Chapter 6: Competition for Resources between Avian and Small Skinks .......... 126
6.1. INTRODUCTION .................................................................................. 126
6.2. METHODS ............................................................................................ 129
   6.2.1. Animal sampling ............................................................................. 129
   6.2.2. Data Analysis ................................................................................ 130
6.3. RESULTS .............................................................................................. 130
   6.3.1. Skink Abundance and Diversity ....................................................... 130
   6.3.2. Seasonal skink abundance and diversity .......................................... 130
   6.3.3. Identification of Avian Competitors ................................................. 131
   6.3.4. Avian Competitor Abundance and Diversity ..................................... 134
   6.3.5. Avian Competitor Seasonal Abundance and Diversity ................. 140
6.4. DISCUSSION ....................................................................................... 150

Chapter 7. Interaction Between Avian and Skinks: Predator and Prey ............ 157
7.1. INTRODUCTION .................................................................................. 157
7.2. METHODS ............................................................................................ 159
   7.2.1. Animal Sampling ............................................................................. 160
   7.2.3. Predation rates .............................................................................. 160
   7.2.4. Analyses of predation data ............................................................. 163
7.3 RESULTS .............................................................................................. 164
   7.3.1. Skink Abundance and Diversity ....................................................... 164
   7.3.1. Avian Predator Abundance and Diversity ........................................ 164
   7.3.2. Predator/Prey Interaction ................................................................. 167
   7.3.3. Predation Rates ............................................................................ 168
       7.3.3.1. Spatial ..................................................................................... 168
       7.3.3.2. Spatial and Temporal Attacks ................................................... 174
7.3.4. Attack Correlations..................................................................................................... 178

7.4. DISCUSSION.................................................................................................................. 179

7.4.1. Avian Abundance and Diversity .............................................................................. 179

7.4.2. Predator/Prey Interaction...................................................................................... 182

7.4.3. Predation Rates.................................................................................................... 187

Chapter 8. Final Discussion.............................................................................................. 193

References.......................................................................................................................... 207
### Table of Tables

**Table 3.1.** Mean number, standard deviation and level of significance (* donates significance at 0.05) of the total number of arthropods encountered across all the edge and core sites sampled in woodland remnants in peri-urban north-western Sydney. Included in table is species habitat niche as either terrestrial (T), aerial/arboreal (A) or aquatic (W). ................................................................. 44

**Table 3.2.** Mean number, standard deviation and level of significance (* donates significance at 0.01; (** donates significance at 0.001) of the total number of skinks encountered across all the edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, during autumn, spring 2001, and summer 2002..................................................................................... 47

**Figure 3.6.** Rank abundance curves (and corresponding skink species) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, during autumn, spring 2001, and summer 2002. Plotted lines are linear trend-lines (edge, \( R^2 = 0.98 \); core, \( R^2 = 0.95 \)). .................. 49

**Table 3.3.** Mean number, standard deviation and level of significance (* donates significance at 0.01) of the total number of birds encountered across all the edge and core sites sampled in woodland remnants in peri-urban north-western Sydney. Included in table is species size: Large (L; >40cm), Medium (M; 20 – 40cm) and Small (S; <20cm), as well as whether they are endemic (E) or introduced (I).................................................................................................................... 52

**Table 5.1.** Data collected on dietary intake of *L. guichenoti*. The information is shown as percentage of volume of all guts observed in these skinks. Bolded areas indicate prey items common across all studies............................ 98

**Table 5.2.** Data collected on dietary intake of *L. delicata*. The information is shown as a percentage of volume of all guts observed in these skinks. The * indicates that while prey items where observed no quantitative data were available. Bolded areas indicate prey items common across all studies................................................................. 99

**Table 5.3.** Mean, standard deviation and t-test (* donates significance at 0.05) of the total number of arthropods collected and were determined to match the dietary size range consumed by the two Lampropholis skinks, encountered across all the edge and core sites in peri-urban north-western Sydney, 2001. Included in table is species habitat niche as either terrestrial (T), aerial/arboreal (A) or aquatic (W). ................................................................................................................... 100

**Table 5.4.** Spearman’s rank correlation, conducted on various combinations of the 19 arthropod groups with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001 ........................................................................................... 107

**Table 5.5.** Spearman’s rank correlation, conducted on various combinations of the 9 arthropod size groups with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney 2001 ........................................................................................... 111
Table 5.6. Mean, standard deviation and t-test of the total number of arthropods (within the most commonly consumed prey size) encountered across the edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001. Included in table is species habitat niche as either terrestrial (T), aerial/arboreal (A) or aquatic (W).

Table 5.7. Spearman’s rank correlation, conducted on various combinations of the 11 arthropod groups (determined by skink dietary preference in both consummation and size) with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney 2001.

Table 6.2. List of potential avian competitors, their foraging behaviour (including niche) and other behaviour which could impact on skink numbers in edge and core areas of woodland remnants in peri-urban north-western Sydney. Included in table is species size: Large (L; >40cm), Medium (M; 20 – 40cm) and Small (S; <20cm), as well as whether they are endemic (E) or introduced (I). Other abbreviations used in the table include: Y – yes, N- No and S – sometimes.

Table 6.3. Mean, standard deviation and t-test (* donates significance at 0.05) of the competitive avian species, encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

Table 6.4. Spearman’s rank correlation, conducted on various combinations of the 23 avian species with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001/02.

Table 6.5. Seasonal number of competitive avians encountered across all core and edge of woodland remnants in peri-urban north-western Sydney ($\chi^2 = 0.023$). The number of different species encountered is shown in brackets.

Table 6.6. Seasonal mean number, standard deviation and t-test (* donates significance at 0.05) of the competitive avian species, encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

Table 6.7. Spearman’s rank correlation, conducted on various combinations of the 23 competitive avian species with skink numbers, during spring. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001.

Table 6.8. Spearman’s rank correlation, conducted on various combinations of the 23 competitive avian species with skink numbers, during summer. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2002.

Table 6.9. Spearman’s rank correlation, conducted on various combinations of the 23 competitive avian species with skink numbers, during autumn. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001.
Table 7.1. Mean number, standard deviation and t-test (* donates significance at 0.05) of the predatory avian species, encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02. 167

Table 7.2. Spearman’s rank correlation, conducted on various combination of the 7 predator avian species with skink numbers. The results reported are the combinations (donated by X) that best explain skink distribution throughout edge and core areas of. 168

Table 7.3. Two-way ANOVA results for avian attacks across all edge and core sites. 171

Table 7.4. Three-way ANOVA results table for avian attacks based on the size of the decoy, across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02 (*** donates significance at 0.001; NS donates not significant). 173

Table 7.5. Two-way ANOVA results table for avian attacks on decoys, spatial and temporally, across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02 (* donates significance at 0.05. NS donates not significant). 175

Table 7.6. Three-way ANOVA results table for avian attacks on size structure, spatial and temporally, across all edge and core sites woodland remnants in peri-urban north-western Sydney, 2001/02 (* donates significant at 0.05; *** donates significant at 0.001; NS donates not significant). 176

Table 7.7. Tukey’s HSD applied to both spatial and temporal attacks based on the size of the decoy across all edge and core sites of woodland remnants in peri-urban north-western Sydney (* donates significant at 0.05; ** donates significant at 0.01; *** donates significant at 0.001; NS donates not significant). 177

Table 8.1. Distribution of animal groups across remnants and adjacent areas. Lines represent presence in relatively greater numbers (▬), presence in fewer numbers than elsewhere (---), and absence ( ). 193
Table of Figures

Figure 2.1. Map highlighting the Cumberland Plain region. The inset map indicates its location in relation to Sydney, NSW (Benson, et al. 1996).......................................................................................................................... 25

Figure 2.2. Map of the study area showing edge sites (1-4) and core sites (5-8). Inset shows the study site in relation to Sydney, NSW.................................................................................................................. 29

Figure 2.3. Average monthly ambient temperature ($^\circ$C) for the study period, recorded at the Hawkesbury campus of University of Western Sydney (♦ - 1998, ■ - 1999, ▲ - 2000, ★ - 2001, ● - 2002)................................................................................................................... 32

Figure 2.4. Average monthly rainfall (mm) for the study period, recorded at the Hawkesbury campus of University of Western Sydney (■ - 1998, ■ - 1999, ■ - 2000, ■ - 2001, ■ - 2002). ..................32

Figure 3.1. Number of arthropods encountered across edge (■) and core (■) sites of remnants of woodland remnants in peri-urban north-western Sydney, autumn 2001. ..................................................... 43

Figure 3.2. MDS plots (derived from Bray-Curtis similarity) based on arthropod abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed the greatest degree of similarity as a group (average 71.15%). Core sites were less similar than edge sites (average 66.47%). There was a significant similarity between edge and core sites ($R = 0.094, P = 0.29$). .......................................................... 44

Figure 3.3. Rank abundance curves (and corresponding arthropod species) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001. Plotted lines are linear trend-lines (edge, $R^2 = 0.97$; core, $R^2 = 0.91$).............................................................................. 45

Figure 3.4. Total number of individual skinks and species observed across edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, 2001/02.......................................................... 47

Figure 3.5. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Core sites displayed the greatest degree of similarity as a group (average 91.1%). Edge sites were less similar than core sites (average 71.8%). There is no significant similarity between edge and core sites ($R = 0.635, P = 0.029$).48

Figure 3.6. Rank abundance curves (and corresponding skink species) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, during autumn, spring 2001, and summer 2002. Plotted lines are linear trend-lines (edge, $R^2 = 0.98$; core, $R^2 = 0.95$).................50

Figure 3.7 Avian abundance and diversity across edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney.......................................................... 53
Figure 3.8. Rank abundance curves (and corresponding avian species) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney. Plotted lines are linear trend-lines (edge, \( R^2 = 0.98 \); core, \( R^2 = 0.98 \)).

Figure 3.9. MDS plots (derived from Bray-Curtis similarity) based on avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed greatest similarity as a group (average 58.9%). Core sites were slightly less similar than edges (average 58.4%). The site types are well separated (\( R = 0.94, P = 0.029 \)).

Figure 3.11. MDS plots (derived from Bray-Curtis similarity) based on the overall community (of arthropod, skink and avian) abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Sites were equivalently similar (edge average 58.9%; core average 58.9%). There was no significant similarity between edge and core sites (\( R = 0.969, P = 0.029 \)).

Figure 4.3. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) in 1999. Core sites displayed greatest similarity as a group (average 97.8%). Edge sites were less similar than core sites (average 69.4%). There were differences in abundance and diversity between edge and core sites (\( R = 0.417, P = 0.029 \)).

Figure 4.4. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) in 2001/02. Core sites displayed greatest similarity as a group (average 92.2%). Edge sites were less similar than core sites (average 73.2%). There were differences in abundance and diversity (\( R = 0.646, P = 0.029 \)).

Figure 4.5. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for autumn 1999. Core sites displayed greatest similarity as a group (average 90%). Edge sites were less similar than core sites (average 60.8%). Edges sites had greater similarity to core sites than to each other (\( R = 0.141, P = 0.143 \)).

Figure 4.6. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for autumn 2001. Core sites displayed greatest similarity as a group (average 76.8%). Edge sites were less similar than core sites (average 67.5%). Both edge and core sites were similar (\( R = 0.281, P = 0.057 \)).

Figure 4.7. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for spring 1999. Core sites displayed greatest similarity as a group (average 91.1%). Edge sites were less similar than core sites (average 65.3%). There is no similarity between edge and core sites (\( R = 0.656, P = 0.029 \)).

Figure 4.8. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for spring 2001. Core sites displayed greatest similarity as a group (average 93.2%). Edge sites were less similar than core sites (average 70.6%). There is no similarity between edge and core sites (\( R = 0.583, P = 0.029 \))..

Figure 4.9. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for summer 2002. Core sites displayed greatest similarity as a group (average 90%). Edge sites were less similar than core sites (average 70.7%). There was a degree of similarity between the core and the edge sites (\( R = 0.115, P = 0.2 \)).
Figure 5.1. Total number of individuals (within order groups) of arthropods consistent with the dietary preferences of both L. guichenoti and L. delicata encountered across all edge (■) and core (▲) sites in peri-urban north-western Sydney, 2001 ............................................................ 101

Figure 5.2. The total number of arthropods collected across all edge (■) and core (▲) sites in peri-urban north-western Sydney, and within each size category (width and length) of L. guichenoti and L. delicata prey consumed ................................................................................................. 102

Figure 5.3. Mean number (S.E. and S.D.) of arthropods consistent with L. guichenoti and L. delicata dietary items encountered across all edge (■) and core (▲) sites in peri-urban north-western Sydney, 2001 .......................................................................................................................... 103

Figure 5.4. MDS plots (derived from Bray-Curtis similarity) based on arthropod (identified as skink dietary items) abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites were similar as a group on average 78.2%. Core sites averaged a 76.2% similarity. There was similarity between edge and core sites (R = 0.188, P = 0.2).............................................. 103

Figure 5.5. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) in peri-urban north-western Sydney, 2001, for arthropods consumed by L. guichenoti and L. delicata. Plotted lines are linear trend-lines (edge, R^2 = 0.99; core, R^2 = 0.97). ..................................... 104

Figure 5.6. Mean (S.E. and S.D.) of arthropod abundance consistent with L. guichenoti and L. delicata dietary items and also match the preferred size range, encountered across all edge (■) and core (▲) sites in peri-urban north-western Sydney, 2001................................................... 106

Figure 5.7. Number of arthropods and orders that have been reported to be consumed by L. guichenoti and L. delicata and are within the most commonly consumed size range, encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001 ........................................................................................................... 108

Figure 5.8. MDS plots (derived from Bray-Curtis similarity) based on arthropod abundance and diversity (and overlapping prey size preference), collected from the 4 edge (■) and 4 core sites (▲). Edge sites were similar as a group (average 82%). Core sites averaged 82.9% similarity. There was similarity between edge and core sites (R = 0.09, P = 0.229). ................................ 108

Figure 5.9. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001, for arthropods within the preferred size range (by order) consumed by L. guichenoti and L. delicata. Plotted lines are linear trend-lines (edge, R^2 = 0.99; core, R^2 = 0.96)........ 109

Figure 5.10. Number of arthropods, as defined by L. guichenoti and L. delicata’s dietary intake and preferred size range (width and length) encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001 .............................................. 110

Figure 5.11. Rank abundance curves (and corresponding size) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001, for arthropods consumed by L. guichenoti and L. delicata. Plotted lines are linear trend-lines (edge, R^2 = 0.923; core, R^2 = 0.923)....... 112
Figure 5.12. Mean (S.E. and S.D.) of the total number of arthropods within the preferred size range consumed by L. guichenoti and L. delicata, encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001 ......................................................... 113

Figure 5.13. Number of arthropod individuals, in order group, most commonly consumed by L. guichenoti and L. delicata, encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001 .......................................................... 114

Figure 5.14. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) in of woodland remnants -urban north-western Sydney, 2001, for arthropods within the commonly taken size range by L. guichenoti and L. delicata. Plotted lines are linear trend. ....................... 115

Figure 5.15. MDS plots (derived from Bray-Curtis similarity) based on arthropod abundance and diversity (within the most commonly consumed prey size), collected from the 4 edge (■) and 4 core sites (▲). Edge sites were similar as a group on average 74.3%. Core sites averaged 83.7% similarity. There was similarity between edge and core sites ($R = 0.052, P = 0.686$). 116

Figure 6.1. Mean number (S.E. and S.D.) of skinks for the seasons spring, summer and autumn, encountered across edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001/02....................................................................................................... 131

Figure 6.2. Total avian competitor abundance and diversity encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001/02................................. 135

Figure 6.3. Mean number (S.E. and S.D.) of competitive birds encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001/02...................... 136

Figure 6.4. MDS plots (derived from Bray-Curtis similarity) based on avian competitor abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed a slightly greater degree of similarity as a group (average 63.7%). Core sites were less similar (average 60.3%). There is no similarity between edge and core sites of remnants ($R = 0.875, P = 0.029$). ............................................................................................................. 136

Figure 6.5. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001/02 for competitive avian species. Plotted lines are linear trend-lines. .......................................................... 137

Figure 6.6. Mean number (S.E. and S.D.) of competitive avian for the seasons spring, autumn 2001 and summer 2002, encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney .......................................................... 141

Figure 6.7. MDS plots (derived from Bray-Curtis similarity) based on competitor avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲), during spring. Edge sites displayed greatest similarity as a group (average 64.3%). Core sites were less similar than edge sites (average 53.6%). Sites were similar ($R = 0.063, P = 0.343$). .......................................................... 145

Figure 6.8. MDS plots (derived from Bray-Curtis similarity) based on competitor avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲), during summer. Edge sites
displayed greatest similarity as a group (average 62.4%). Core sites were less similar than edge sites (average 52.7%). There is no similarity between edge and core sites ($R = 0.552, P = 0.029$). 

Figure 6.9. MDS plots (derived from Bray-Curtis similarity) based on competitor avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲), during autumn. Core sites displayed greatest similarity as a group (average 46.2%). Edge sites were less similar than core sites (average 42%). Sites were not similar ($R = 0.865, P = 0.029$). 

Figure 7.1. Anatomical strike zones on small skinks by avian predators. Identification of beak marks in these three areas (head, torso and tail) were recorded and analysed. 

Figure 7.2. Mean number (SD and SE) of predatory birds encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02. 

Figure 7.3. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001/02, for predatory avian. Plotted lines are linear trend-lines (edge, $R^2 = 0.85$; core, $R^2 = 0.99$). 

Figure 7.4. MDS plots (derived from Bray-Curtis similarity) based on predator avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed greatest similarity as a group (average 72.7%). Core sites were less similar than edge sites (average 56.8%). There is no similarity between edge and core sites ($R = 0.427, P < 0.029$). 

Figure 7.5. Mean number (SD and SE) of attacks by birds on decoys across all edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, 2001/02. 

Figure 7.6. Mean number (SD and SE) of attacks based on anatomical location of attack on decoys, across all edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, 2001/02. 

Figure 7.7. Mean number (SD and SE) of attacks on decoys both temporally and spatially across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02. 

Figure 7.8. Mean number (SD and SE) of attacks, location of attack on the decoys and size of decoy, temporally across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02. 

Figure 7.9. Mean number (SD and SE) of attacks on decoys, both temporally and spatially, across all edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, 2001/02.
Figure 7.10. Mean number (SD and SE) of attacks based on the size of the decoy, both temporally and spatially, across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

Figure 7.11. Correlations between skink (prey) numbers and the number of attacks on decoys ($r = -0.553$); avian (predator) numbers with skink numbers ($r = -0.741$); avian numbers with the number of attacks on decoys ($r = 0.808$).
## Table of Plates

**Plate 2.1.** Edge Site 1. This site is characterised by the presence of powerlines………………..30

**Plate 2.2.** Edge Site 2. This picture epitomise the edge sites, i.e. grassland meeting bushland……..30

**Plate 2.3.** Core Site 6 showing *Melaleuca spp.* Forest………………………………………………..31

**Plate 2.4.** Core Site 7 showing *Eucalypt spp.* Forest………………………………………………….31

**Plate 7.1.** Decoys shown represent juvenile, sub-adult and adult ………………………………….163

**Plate 7.2.** Adult decoy after avian attack …………………………………………………………………163
Abstract

This study focused on the interactions between small skinks and their major predators/competitors (birds) and prey (arthropods) in core and edge areas of small, long established remnant Cumberland Plain woodlands of Richmond, New South Wales, Australia. Eight study sites were selected (4 edge and 4 core) within the peri-urban environment to compare the abundance and diversity of small skinks, birds and arthropods.

Of the three taxa, only arthropods maintained a similar abundance and diversity between edge and core areas. Birds and skinks were either in lower numbers in the perimeter areas (skinks), or were interior/perimeter specialists (birds).

Arthropod diversity and abundance of preferred skink prey, was also examined. It was concluded that the distribution of arthropod prey was similar between core and edge areas, and therefore, was not considered to have an influence on small skinks’ ability to inhabit edges. However, large, aggressive/noisy birds (including skink and small bird predators) dominated edge areas.

Those birds encountered in the edge foraged in a variety of niches, such as on the ground or they swooped from vantage points. This, coupled with other anti-competitor behaviour (e.g. noise, aggression, flocking), placed these birds in proximity to skinks in the edge areas. However, as most of these birds were also predators of skinks, it was concluded that the evidence supported a predator/prey relationship in the perimeter area, rather than a competitive one. This was supported
by predation rates on skinks, using decoys. Birds preyed on small skink in greater numbers in the perimeter of woodland remnants than in their interior. This predation pressure was sustained throughout the year.

It was concluded that predation and/or displacement of skinks and small birds resulted in lower numbers being observed in edge compared to core areas.

This study demonstrated that old, small remnants not continually exposed to major disturbances (e.g. logging, agricultural practices) can re-establish stability in terms of environmental conditions. However, a stable environment or a single taxonomic group does not necessarily predict the response individual taxa will have to edge habitats and that this can alter the interactions between dependent groups such as prey/predator or competitors.
Chapter 1. General Introduction.

1.1. Introduction.

On a global scale habitat loss and fragmentation has become one of the most perplexing problems facing ecologists (Garden et al., 2006). In Australia alone, land clearance in 1999 was estimated to have been approximately 470,000 ha (Australian Bureau of Statistics, 2002).

Since European settlement, Australian authorities have had to balance the demand for cleared land for European activities with the need to preserve land for endemic flora and fauna (Fox, 1990). Traditionally humans won the debate, taking the most profitable land for their own use and leaving the landscape dotted with small patchy remnants (Wilcox & Murphy, 1985; Burgman & Lindenmayer, 1998; Mac Nally, 1999). For example, in New South Wales 30% of the state has been cleared and replaced with anthropogenic landscapes (Australian Bureau of Statistics, 2002). This phenomenon has had detrimental impacts on biodiversity, and has been linked to an increase in extinction rates, in the remaining endemic landscape (Ewers & Didham, 2006).

These remnants develop two structurally and functionally different areas within them: edges and interiors (Laurance & Yensen, 1991; Saunders et al., 1991; Faaborg et al., 1995). According to Murcia (p58, 1995), an edge occurs when “… two adjacent ecosystems …are separated by an abrupt transition…” Edges have become of interest to ecologists because they act as a conduit that allows an exchange of
energy, nutrients and competitive species to move between the two systems (Murcia, 1995). The result of this is that environmental conditions can fluctuate within the edge in response to the influence of the surrounding ecosystems, until inevitably the edge’s condition impacts on the areas it connects (Ewers & Didham, 2006). These effects are referred to as edge effects.

The greatest impacts are frequently experienced in edge areas. These perimeters often become highly modified, with altered ecological processes (e.g. microclimate, water regimes) so that they resemble neither of the adjoining systems (Saunders et al., 1991; Ryszkowski, 1992; Wiens, 1992; Haila et al., 1993). This, in turn, can be detrimental to the endemic species that occupy such areas, as they may find the edge inhospitable. Such impacts may also have a negative effect throughout the adjoining systems. It is perhaps for this reason that many ecologists are most concerned with the overall effect that edges have on the interior areas and the overall ecosystem functioning of native remnants (Murcia 1995; Ewers & Didham, 2006).

Edges are becoming more prevalent in the landscape, as the human population increases and reduce native vegetation in their wake. It has been estimated that by the year 2010 humans will have urbanised 51.3% of the land’s surface (United Nations, 2004). As the landscape becomes increasingly fragmented remnant size to edge area increases (Flather & Bevers, 2002). It will, therefore, become increasingly important to understand the ecology of edges (Saunders et al., 1991; Murcia, 1995; Demaynadier & Hunter, 1998; Voss & Chardon, 1998; Woodroffe & Ginsberg, 1998; Cadenasso et al., 2003a).
1.2. Edge Effects

1.2.1 Abiotic impacts on flora and fauna.

As previously stated edges act as an area of interchange of abiotic elements between the ecosystems they connect (Cadenasso et al., 2003a). The result is that edge environments are often highly modified, with altered ecological processes (e.g. microclimate, water regimes), and resemble neither of the adjoining systems (Debinski & Holt, 2000). The consequences may be detrimental to the density and dispersal of some species (Cadenasso & Pickett, 2001).

1.2.1.1 Microclimate.

The variation in microclimate between interior areas of remnants and the neighbouring ecosystems is often stark. For example, forested areas have a relatively uniform, cool and moist environment, with limited light penetration. This is in contrast to other vegetation types, such as field crops, which have a more structured biomass (Gieger, 1965; Tscharntke et al., 2005b). In cropped areas greater solar energy reaches the ground during the day, and this may result in sporadic changes to air and ground temperatures (Mader, 1984; Saunders et al., 1991). At the interface between natural and altered areas, microclimate will oscillate between the two different systems, building up a temperature gradient, fluctuating light intensity and different air and soil moisture levels (Matlack, 1993; Young & Mitchell, 1994; Harper et al., 2005). These altered conditions have the potential to cause a domino effect of changes on edge inhabitants (Saunders et al., 1991; Murcia, 1995; McLeod & Gates, 1998). For example, arthropod diversity may decline under altered
microclimatic conditions (Bromham et al., 1999; Davies et al., 2001; Foggo et al., 2001).

The magnitude of these effects differs with orientation, season and latitude (Chen et al., 1990; Matlack, 1993; Young & Mitchell, 1994; Cadenasso et al., 2003a). Young and Mitchell (1994) determined that microclimate regimes within the edge of fragmented Podocarp-Broadleaf forests (New Zealand) were adversely affected only in summer and they observed that southerly facing edges were more greatly impacted than northerly ones. In mixed-mesophytic forests (USA) the south and west facing edges displayed greater microclimate fluctuations, than the opposing northern and eastern ones (Gehlhausen et al., 2000).

Factors, such as increased light intensity, may dictate local ambient temperatures (Chen et al., 1990; Matlack, 1993; Young & Mitchell, 1994; Harper et al., 2005). Increased solar radiation can affect nutrient cycling and increased soil temperature. In turn, soil temperature directly modifies micro-organism and invertebrate activity, litter decomposition rates and soil moisture (Gieger, 1965; Davies et al., 2001). For example, increased air temperature and radiation levels have been recorded in the edges between grazed pasture land and native forests, have caused changes to the vegetation structure in these areas (e.g. Waikato region, New Zealand; Denyer et al., 2006).

In the presence of altered light intensity (affecting photosynthetic rates), soil chemistry and temperature can affect seed germination, mortality and consequently plant recruitment (Chen et al., 1990; Burke & Nol, 1998; Tomimatsu & Ohara,
In turn, nutrient cycling and altered light patterns may result in local extinction, or the species may be restricted to interior areas (Hill & Curran, 2005). Specialist species, such as shade-tolerant plants (e.g. mosses and ferns), often have this pattern of distribution (Soulé et al., 1991; Williams-Linera et al., 2005).

Changes in wind velocity may also have an effect on vegetation structure, and wind speed can increase substantially within edge zones (Ranney et al., 1981; Lovejoy et al., 1986; Harper et al., 2005). In Sweden, there have been reports of edges experiencing a five-fold increase in average wind speed, compared to the interior of forests (Odin, 1976). Plant foliage, previously protected from wind exposure, is vulnerable to physical damage from wind pruning and wind throw (Ranney et al., 1981; Lovejoy et al., 1986). This mechanical damage may impact upon tree mortality rates, increased leaf litter and have the potential to further alter the quality of habitat available for fauna. For example, in spruce forests in Sweden, there was a marked increase (between 30 - 98%) in tree mortality in fragments due to the increase in both wind exposure and speed (Essen, 1994). In the southern hemisphere, in a study conducted in the Atherton Tablelands (Australia), it was observed that in rainforest edge areas, there was a significant increase in log numbers, compared to core areas. This was attributed to an increase in wind shear (Sumner et al., 1999).

Increased wind speed may also influence the movement of lose particles such as dust, seeds and pollutants (Forman & Alexander, 1998; Weathers et al., 2001). Transport of soil particles between ecosystems can also cause a soil gradient at the edge of the remnant, and this may affect nutrient levels (Saunders et al. 1991;
Forman & Alexander 1998). Wind transfer of seeds from exotic vegetation can be introduced to the seed bank of the edge assemblage, and this may alter the composition and/or the genetic integrity of the vegetation association (Cadenasso & Pickett, 2001). Conversely, the wind may carry seeds out of the remnant into unsuitable habitats and prevent the establishment of interior species (Hobbes & Atkins, 1989).

There has been one report, however, that indicated that some interior seeds may benefit from being transplanted into alien landscapes. In the highland area of Chiapas (Mexico), the success of various oak trees’ *Quercus sp.* germination was tested in the interior of native remnants, on edges and in the adjacent grasslands. It was determined that acorns that were able to pass from the core through the edge and into the grasslands had a more than 50% better chance of germination than those remaining in the interior or perimeter areas (Lopez-Barrera & Newton, 2005).

Wind turbulence can also affect the spread of disease and the transfer of insects throughout the remnant (Saunders, *et al.* 1991). It is also probable that increased wind velocity could interfere with pheromones and/or insect and bird chorus. Changed wind turbulence may also affect evapotranspiration rates, and thus increase the chances of desiccation (Saunders *et al.*, 1991; Kremsater & Bunnell, 1999).

Wind momentum can aid in the spread of chemical compounds across the edge, such as those used in fertilising crops. This may further influence the native vegetation structure (Hester & Hobbs, 1992).
Measuring the impacts of microclimatic changes on species survival can be problematic. The results of previous studies have indicated that the extent to which these effects may influence remnants is highly variable and that the depth of the impact is dependent upon the effect measured. For example, Young and Mitchell (1994) found gross microclimatic effects penetrated only to a depth of 50m from the edge, regardless of the remnant size. Conversely in Douglas-fir forests (North America), wind effects extended 120m into the forest, while temperature flux occurred up to 180m from the edge (Chen et al., 1990).

Microclimatic effects in edge areas have generally been restricted to vegetation, and vegetation structure. Other taxa have often been excluded from these studies (the exception being arthropods; Bromham et al., 1999; Davies et al., 2001; Fogg et al., 2001) on the basis that they are only indirectly affected by microclimate by way of habitat and food loss. However, temperature fluctuations and increased wind velocity could directly affect some taxa, such as amphibians (Gray et al., 2004).

1.2.1.2. Water Regimes.

Altered hydrological cycles may also occur at the interface between landscape types (Forman & Alexander, 1998). Vegetation reduction results in altered water pathways (Kapos, 1989). In turn, this can inhibit infiltration (Bell, 1988) and the resultant decrease in water penetration may cause mortality in deep-rooted perennial species, and aid in the establishment of more shallow rooted plants (Hornbeck, 1973; Simons, 1989; Thrall et al., 2005). Such scenarios would result in a change in species composition over time (Hill & Curran, 2005). The problem may be exacerbated by increased surface water that may result in more intensive run-off and associated
topsoil loss. Such erosion may be more prevalent as drainage patterns are altered (Bormann et al., 1974; Renison et al., 2004). Changed ground water dynamics caused by removal of deep-rooted vegetation may also cause water tables to rise (Hurditch, 1995). The associated elevated salinity levels may induce further plant loss (Peck, 1978; Saunders, 1994), and change community composition that could result in more salt tolerant species assemblages (Bell, 1988).

Changes in surface and soil moisture also affect decomposition rates of leaf litter, dispersal of seeds, and decline in the habitat for ground dwelling fauna, such as Coleoptera (Burke & Nol, 1998) and Collembola (Ferguson, 2004a).

1.2.1.3. Barrier Effects.

Edges may act as a conduit for some species to expand their range. Conversely the benefit may only be to ‘invasive’ taxa, while hindering the dispersal of others by acting as a barrier to migration (Tiebout & Anderson, 1997; Parker et al., 2005).

As mentioned previously, edge habitats can affect a plant’s ability to disperse seeds into new profitable areas. In animals, reduced movement across the edge is particularly restrictive to species with specialist feeding requirements, near the margins of their geographical range, or who lack the ability to transverse open territory, (e.g. arboreal mammals; Howe, 1984; Laurance & Laurance, 1999). In such cases the edge acts as a barrier, isolating them from other compatible habitats. Conversely, specialist species may be prevented from accessing a remnant via the more hostile edge (Yahner 1988).
The barrier effect can also delineate territorial boundaries, or an animal species’ (particularly large mammals) home range. The range may be altered, shrunk, lost or distorted (Woodroffe & Ginsberg, 1998; van der Ree & Bennett, 2003). Despite this, the greatest risk to dispersal may be the anthropogenic activities that occur immediately adjacent to the edge. For example, Ashley and Robinson (1996) observed that roads bordering remnants increased frog and turtle mortality (road kill), as they attempted migration. Ramp et al. (2006) determined that native Australian mammals crossing roads in the Royal National Park were killed at a rate of 0.011 per km per day, while bird fatality was recorded at 0.023 per km per day. Undoubtedly edges can contribute to the barrier effect of fragmented areas. However, the extent of the problem may be over-emphasised. It is likely that migration is more affected by remnant isolation. Distance between remnants can be a prohibitive factor that edge has limited impact upon. For example, some taxa are unable to transverse a gap of 30 to 40 m (dung and carrion beetles; Klein, 1989) between suitable habitats. Others are inhibited by larger expanses (80-150 m; Laurance et al., 2002). These ‘gaps’ between suitable habitat can be exacerbated by the surrounding matrix. For example, some taxa are reluctant to move across open areas, into new suitable territories (e.g. insect-gleaning bats; Kalko, 1998), no matter the distance. It is, therefore, more likely that these factors influence dispersal of native species, than actual edge habitats.  

1.2.1.4. Age.

Recently created edges may serve to increase species diversity and richness temporarily, but with time, abundance and diversity will decline to a new equilibrium
(Essen 1994; Hagen et al. 1996). For example, Hagen, et al. (1996) observed that in habitat fragments, bird abundance increased within a short time of initial edge creation but inevitably declined with time. Conversely, in eastern Finland, wood-rotting fungi in the edges of forests and peatlands have not fully recovered from the initial edge creation, even after 120 years (Siitonen et al., 2005).

The true impact of edge age is often not immediately obvious. Essen (1994) demonstrated that conifer tree mortality approximately doubled in 1.3 years after an edge was created. Conversely, amphibian and reptile diversity has been shown to decrease in newly created edges, but increased over time, and ultimately declined again as regrowth became more prevalent (Lunney et al., 1991; Demaynadier & Hunter, 1998).

1.1.2. Biotic Edge Effects.

Abiotic changes often translate into biological changes. As previously indicated, altered microclimate in edge areas can alter the native vegetation structure, and subsequently have an influence on habitat availability for endemic animals. The result may be localised extinction of some species whilst increasing the abundance of others, thereby altering the ecosystem function (Shaffer, 1981; Ewers & Didham, 2006).

1.1.2.1. Abundance and Diversity.

Historically, edges were considered ideal for enhancing species richness in remnants. Leopold (1933) proposed that the connection of ecosystems created a wider diversity
in edges, than in the core areas of the remnant, due to species invasion from surrounding ecosystems. Based upon this premise, the impact on adjacent systems would be advantageous to the population dynamics and ecological processes of remnants, as migration prevents system collapse. This effect is often referred to as the rescue effect (Xu et al., 2006).

Increased species richness may not be beneficial to a system. Mader (1984) speculated that edges are dominated by highly mobile and pioneering species. Such ‘invaders’ often usurp endemic taxa and cause localised extinction. Honnay et al. (2002) demonstrated that both naturally and anthropogenic formed edges are dominated by competitive and light seeking plants, to the exclusion of some shade-seeking, less competitive species. They also determined that the invasion of these new plant species was limited to edge areas, as the remaining taller native trees prevented their spread. It was speculated that this indicated that edges allow a different assemblage of species to exist within the altered habitat, and created distinctly ‘edge’ and ‘interior’ species (Ranney et al., 1981; Panetta & Hopkins, 1991; Burke & Nol, 1998).

Altered vegetation structure in edge areas can influence fauna diversity, abundance and distribution (Soulé & Gilpin, 1991; Saunders, 1993; How & Dell, 1994; Jellinek et al., 2004), as habitat is lost for some faunal species, while benefiting others (Moilanen & Hanski, 1998). For example, studies on amphibians have revealed that loss of native vegetation and the introduction of agriculture, left ‘hard’ edges that were devoid of appropriate habitat for sustainable populations of frogs and salamanders (Demaynadier & Hunter, 1998; Voss & Chardon, 1998). Other
researchers (e.g. Hadden & Westbrooke 1996) have also observed that herpetofaunal richness increased with distance from the edge of the remnant, where weed infestation and disturbance decreased. In contrast, other studies have revealed that endemic edge specialist species emerge. Berry (2001) observed that avian species richness in edge areas consisted predominantly of endemic birds that favoured the greater foraging capacity in the adjacent open country. Generalist birds have also been reported to survive equally well, in both edge and interior areas of remnants, and may out-compete some of the specialist species (Bentley & Catterall, 1997).

Other species have been able to adapt to changes between edge and core for specific purposes. Gravid and shedding black rat snakes *Elaphe obsoleta obsoleta*, have a preference for edge habitat for thermoregulation, while non-gravid, non-shedding snakes tend to remain in the interior region, and achieve the same outcome (Blouin-Demers & Weatherhead, 2001).

The ability of species to continue to survive in edge areas may have more to do with the quality of the edge (Yahner 1988). The overall characteristics of the edge, and its surrounding landscape, may have a greater effect on the overall diversity of both fauna and flora communities than on the creation of edge alone. For example, the herbivorous tammar wallaby (*Bettongia penicillata*) utilise the altered vegetation structure on the edge of remnants to supplement their diet, while sheltering in the interior areas (Christensen, 1980). It has also been suggested that both invertebrates and vertebrates may use weeds as protective cover. Ants utilised the edge of montane forest to build their nests in edges but foraged in the matrix surrounding the
edge (Perfecto & Vandermeer, 2002). In *Zostera* seagrass bed fragments crustaceans utilised the edge to rest in while foraging in the adjacent sand (Tanner, 2005).

1.1.2.2 Predation

The modified habitat in edge areas can cause changes to competition, predator/prey and parasitic interactions, as well as overall resource availability (Gates, 1991; Saunders *et al*., 1991). Murcia (1995) used the following example to highlight this effect. Altered light intensity may cause a leaf flush on some plants and attract herbivorous insects into the area. The increase in insect numbers may entice nesting birds into the edge. In turn, these can attract nest predators and brood parasites. As a result the dynamics of the local environment may be changed.

Edge areas provide predators with access into areas from which they might otherwise be excluded (Bommarco & Fagan, 2002; Ferguson, 2004b). Generalist predators, such as carnivores, often occupy a matrix ecosystem and incorporate the remnant/s into their home range. The result may be to increase predation pressure at the interface of the wooded area, and the surrounding ecosystems (Angelstam, 1986; Andrews, 1990). The extent to which these predators can penetrate the remnant via the edge is variable. Goldingay and Whelan (1997) detected feral dogs and cats in only the first 50-200m edge of the remnant, while in a study on black rats it was observed that they foraged in only the first 100m from the edge (Delgado *et al*., 2001). In contrast, studies on bird nest predation have failed to find a decrease in predation rates with distance from the edge into the remnant (e.g. Yahner & Wright, 1985; Angelstam, 1986; Ratti & Reese, 1988; Matthews *et al*., 1999), indicating that these predators did not differentiate between the edge and the interior of remnants.
The introduction of new or increased presence of traditional predators can impact on other coexisting species (Holt, 1987; Sih & Wooster, 1994). Competitive, sympatric or symbiotic associations can be affected by altered predation rates, as generalist predators will ‘switch’ prey choice as the density of preferred prey items are diminished (Murdoch, 1969; Kasparian et al., 2004). For example, Schoener & Spiller, 1999) examined the effects of the introduction of a lizard predator, Anolis sagrei, had on the endemic invertebrate populations. The immediate result was that spider densities (the preferred prey) decreased rapidly after their introduction. That there was a decline in the rate of leaf damage to plants, as herbivorous arthropods (secondary prey) decreased with time, and that this allowed plants to flourish was not immediately obvious.

In contrast, specialist predators are often adversely affected by edge expansion. The variation in species assemblages in edge habitat may reduce prey availability for some predators and those unable to switch diet may themselves become locally extinct (Namba et al., 1999; Fernandez-Juricic et al., 2001).

Edges may also act as a barrier to some endemic predators, preventing them from accessing traditional hunting grounds. Da Fonseca and Robinson (1990) studied Brazilian Atlantic forest remnants, and observed that as remnant size reduced, and edge areas increased, the home range of some of the larger mammalian predators was limited, thereby reducing their foraging activity. This behaviour was also observed in tigers in India, where they were often forced to prey on domesticated animals because they were easier to locate than their native prey (Bagchi & Sankar, 2003).
These findings parallel those of Wilcove (1985) who observed that nest predation rates were dependent on the size of the remnant.

The difficulty for predators in fragmented areas is that edges often reduce their home range, and they are excluded from some areas (da Fonseca & Robinson, 1990). This forces them to forage in a single patch (Howe et al., 1981). The predator can also face extinction as the food source in the single patch is depleted to unsustainable levels (Murdoch & Oaten, 1975; Howe et al., 1981; Namba et al., 1999).

Alternatively, home range fragmentation can create other problems, such as giving endemic top order predators the opportunity to take domesticated animals, bringing the predators into conflict with humans. For example, it has been estimated that fragmentation of the forest home range of spotted hyenas *Crocuta crocuta*, has resulted in them being responsible for 53% of attacks on livestock that occupied the hyenas traditional hunting grounds (Kolowski & Holekamp, 2006).

1.1.3 Anthropogenic Impacts.

Human activity, such as hazard reduction burning, stock grazing and vehicle access, adjacent to remnants can impact heavily on species abundance and diversity (Recher & Lim, 1990). Species assemblages in edge areas can, therefore, be greatly influenced by the anthropogenic activities that occur in the abutted system (Ross et al., 2002). Agricultural practices can be detrimental, for example, chemical drift (in the form of fertilisers and pesticides) stock animals that transverse the edge, altering nutrient cycling, soil composition and succession (Fleischner, 1994; Cornelius & Schultka, 1997; Weathers et al., 2001). Such changes were observed in heathland
edge areas adjacent to cropland in Belgium. These perimeter areas displayed distinct eutrophication characteristics as nitrate levels in the soil altered. This effect was linked to chemical fertilisation of crops that leaked into the native remnant (Piessens et al., 2006).

Grazing can also have an influence on ground dwelling arthropod populations, via trampling and removal of understorey plants (Hadden & Westbrooke, 1996). Both grazed woodlands and pastures have been observed to have fewer species, but a greater abundance of arthropods, than undisturbed areas (Bromham et al., 1999). It would be expected that such an affect would not impact greatly on invertebrate predators, such as lizards and some birds; however, the reverse appears to be the case, with these animals declining in grazed areas (Jones, 1981; Ludwig et al., 2000; James, 2003). Grazing (and vehicle traffic) can cause soil compaction, and destroy understorey plants that are a vital part of ground dwelling herpetofaunal survival (Busack & Bury, 1974; Abensperg-Traun et al., 1996; Hadden & Westbrooke, 1996). Smith et al. (1996) determined that whilst grazing and trampling did not affect overall lizard richness, it influenced the persistence of some in fragmented Western Australian forests. In addition, repetitive events, such as grazing and vehicle passage, can disrupt the social structure of some lizards, hindering mating and other social behaviour (Fischer et al., 2004).

Road edges also leave remnants vulnerable to vehicle assisted pollution. Road traffic contributes to seed dispersal, air turbulence, chemical drift and soil removal (Forman & Alexander, 1998). Traffic noise may also induce edge avoidance by some species. The soil immediately adjacent to roads is often left devoid of moisture due to its
construction and maintenance. This can disrupt animal movement, for example amphibians that need continued moisture to enhance mobility (Marsh & Beckman, 2004).

Alternatively, the relatively warmer, more open ecosystem created by roadways may encourage heliothermic species, such as reptiles, onto the road to bask, a potentially lethal scenario. In some areas, particularly in drier periods, the slightly moister roadside verge may encourage grazing, also with potentially deadly consequences. Maintenance of road verges through mowing and burning, may further impact on local population numbers (Forman & Alexander 1998).

Other frequent disturbances near, or in the edge, such as burning and removal of trees, can impact upon the remnant. Burning as part of hazard reduction, can reduce canopy cover and understorey plants, leaving areas dry and hot, which may be unsuitable for some native species (eg. anurans; McLeod & Gates, 1998), while allowing exotic species, such as the house mouse, *Mus musculus*, to expand their occupancy (Lunney & Ashby, 1987). Regrowth in these and logged areas can often be denser than the original vegetation growth, which may impact on species survival. For example, some lizard species are not found in the same numbers in areas of regrowth as in undisturbed areas (Lunney et al., 1991). Logging and burning can also reduce critical habitat, refuges and access routes for some species (e.g. possums and gliders; Lunney & Ashby, 1987).

Conversely, some species may take advantage of anthropogenic influences and incorporate human-made structures into their habitat. For example, Wegner and
Merriam (1979) observed that white-footed mice, chipmunks and some bird taxa utilised fencerows to facilitate movement between remnants. In Australia, birds often perch on powerlines from which they can mount an attack on prey (Blomberg & Shine, 2000). A range of species (e.g. birds, mammals, reptiles) forage in road verges, paddocks and semi-urban situations (Kitchener & How, 1982) and are, therefore, presumably able to cope with the interface between natural forested areas and adjacent ecosystems.

Edge habitats are complex areas that impact differently upon endemic species. These areas are encroaching on natural systems more as human populations grow, clearing land for their own use. It is desirable that those formulating policy to protect native areas (and indeed those left to implement such policies) are provided with appropriate scientific information to make their decisions effective (Cadenasso et al., 2003a; Ewers & Didham, 2006). However, ultimately researchers struggle to explain the complexity of edge effects. The problem may be that edges are easily defined, but not easily assessed. As Ewers and Didham (2006) pointed out it is the confounding factors (e.g. how long since initial disturbance can equilibrium be reached, some suggest less than 50 years others say more) that may disguise other effects relating to edge and fragmentation. As a result many researchers attempt to explain the gross effects of edges by concentrating on a single impact in a ‘window’ in time, and utilise the information to explain what is occurring throughout the remnant ecosystem (Margules & Nicholls, 1987). While this may be expedient, the conclusions drawn may be substantially erroneous.
A case in point is studies that concentrate on abiotic effects in edges. These parameters have been widely used, and the data are relatively easy to collect compared to biotic characteristics, but they may not be as informative as they are usually only examined in relation to vegetation structure (e.g. Chen et al., 1990; Matlack, 1993; Young & Mitchell, 1994). The results gained from these studies are then often extrapolated to explain species richness for other taxa, by way of habitat and food loss. However, it is possible that edge avoidance by some taxa has nothing to do with these factors. For example, Anderson and Burgin (2002) found that there were significant differences in abundance and diversity of small skinks between the edge and the core of remnants; however, it was not associated with structural characteristics commonly associated with skink distribution.

Accurately defining the real impacts edge effects have on inhabitants of an ecosystem is fraught with difficulty, as different taxa in the same habitat will respond to an impact differently (McLellan et al., 1986). Their response is dependent upon their resilience, ability to disperse and to colonise. However, there appears to be limited data that addresses such systems from a holistic viewpoint, instead an understanding of the ecosystem is built by looking peripherally at a single taxonomic group (e.g. birds, plants, mammals), and the functioning of the ecosystem (both spatially and temporally). Some edge effects are explored frequently, while others rate poorly in research terms. For example, increased predator activity in edge areas has almost exclusively been conducted on avian nest predators (e.g. Wilcove, 1985; Andrén, 1992; Vickery et al., 1992; Nour et al., 1993; Matthews et al., 1999; Lahti, 2001; Kolbe & Janzen, 2002; Piper & Catterall, 2005). In contrast there are limited
data on other significant predation activities, such as birds on skinks, or skinks on arthropods.

In order to gain a better understanding of the impact that edges have on the population dynamics of endemic species, there is a need to investigate a boarder suite of key issues and species (Cadenasso et al., 2003b; Cadenasso et al., 2003a). In the Australian context, reptiles are an integral part of native ecosystems, both as primary and secondary consumers, as well as prey items for other animals (Brown & Nelson, 1993). They are also one of the few vertebrates able to endure in small habitat remnants (How & Dell, 2000) and, when present, this makes them key indicator species of biological health (Burgin, 1993).

Recent studies have indicated that rapid expansion of human development is impacting on reptiles, and they are becoming more vulnerable to decline due to habitat loss (How & Dell, 2000; Driscoll, 2004). For example, there has been a loss of large-sized reptile diversity within the remnant bushland of Perth (Cooper, 1995). In central New South Wales (NSW) in Mallee and woodland areas fragmented by farms, there has been a decline in at least seven species of reptiles, including Ctenotus allotropis and Amphibolurus nobbi, and the latter has been genetically compromised due to isolation (Driscoll, 2004). White and Burgin (2004) reviewed the status of reptiles in selected urban areas of Sydney and concluded that many had become locally extinct (e.g. Lialis burtonis, Pygopus lepidopodus).

Although fragmentation of the natural landscape is detrimental to reptile diversity and abundance, the focus of these studies has tended to be limited to the remnants as
a whole, and not the variation that may occur due to habitat differences within
fragments, that is edge and core areas. Anderson and Burgin (2002) investigated the
effects edges have on small generalist skinks in Cumberland Plain remnants (NSW).
Their results indicated that the abundance and diversity of these skinks were reduced
in edge areas compared to interior regions of the remnants. The causal effect
examined (i.e. changes in habitat characteristics) was shown not to be contributing to
the observed variation.

The skinks investigated by Anderson and Burgin’s (2002) study were two species
\( \textit{Lampropholis guichenoti} \) and \( \textit{L. delicata} \) considered to be common and abundant
throughout much of eastern Australia. These species live in sympatry and have
similar diets, habitat requirements, and they communally nest (Wells, 1981; Cogger
2000). Both species are considered to cope well with disturbance (e.g. Lunney \textit{et al.},
1989; Twigg & Fox, 1991; Fischer & Lindenmayer, 2002). However, fragmentation,
and the consequent edge habitat may have a negative impact upon their abundance
and distribution. Two other small skink species co-occur in these remnants:
\textit{Cryptoblepharus virgatus} and \textit{Saproscincus mustelina} (Anderson & Burgin, 2002).
\textit{Cryptoblepharus virgatus}, a predominately arboreal skink, nests on the ground and
preys on arthropods (Cogger, 2000; Greer & Jefferys, 2001). \textit{Saproscincus
mustelina} is a cryptic terrestrial skink, that also feeds on arthropods and has been
known to utilise the same nesting sites as \textit{L. guichenoti} and \textit{L. delicata} (German,
1986; Cogger 2000).

These small skinks (i.e. \( \leq 55\text{mm} \)) represent an intermediate trophic level, between
birds and arthropods. As a consequence, if such species are in decline there may be
impacts on the population dynamics of both their predators and prey. Price et al., 1980) suggested that decline or change in distribution of members of this trophic level can create instability throughout an ecosystem.

This study was designed to examine the interactions between skinks and their major predators (birds) and prey (arthropods). Both avian and arthropods have been reported to be negatively impacted in edge environments, and this has been shown to lead to changes in their abundance and diversity in remnant areas (e.g. Berry, 2001; Davies et al., 2001). However, it is unclear whether these impacts have been amplified by a decline in skink abundance and diversity.

In this context the aims of this study were to investigate if small skink abundance and diversity are impacted in edge areas by 1) changes in avian predator numbers; 2) identify if avian activity that could alter competitive interactions; and 3) investigate if there are changes in the abundance and diversity of suitable arthropod prey. In exploring these aims an examination of edge and core communities as they exist within the remnants of the Cumberland Plain woodlands, in north west Sydney is undertaken (Chapter 3). Data collected in this section were reused and sub-divided in order to answer the above aims. A comparison of skink abundance and diversity was undertaken to determine if patterns of skink distribution changed temporally (Chapter 4). The interactions that occur in the core and edge of remnants among the three tropic levels investigated (arthropods, skinks and birds) were then explored. Arthropod abundance and diversity were assessed and compared between the two habitat types. These results were then correlated with skink distribution to determine if there were factors that may influence the distribution of skinks (Chapter 5).
The abundance and diversity of insectivorous and omnivorous birds resident in these areas were investigated. Their patterns of distribution within the remnants were then correlated with skink dynamics to assess interactions between these potential competitors (Chapter 6). The numbers and diversity of birds that are skink predators were then compared to skink distribution to investigate if predation rates impacted on skink abundance (Chapter 7).

The focus of the final chapter (Chapter 8) is to provide an overview of the ecosystem dynamics of these remnants, and the impacts created due to the interactions of the taxa co-inhabiting the areas delineated as core and edge.
Chapter 2. Site Description

2.1. Study Area

2.1.2. Cumberland Plain Bushland.

The Cumberland Plain represents 30% of the Sydney Basin (Benson & Howell, 1990; Figure 2.1) and stretches west from Parramatta to Springwood in the Blue Mountains (Australia). It encompasses Richmond to its northwest and Campbelltown/Camden in its southern region (Benson et al., 1996). The area experiences lower rainfall than Sydney’s coastal areas (averages per annum of between 757 and 760 mm per annum; Robinson, 1991). The topography of this region consists of flat to hilly country, with boggy depressions. The underlying geology of the area is Wianamatta Shale (nutrient rich), overlain by Hawkesbury Sandstone (nutrient poor; Benson et al., 1996; French et al., 2000), although the soils are dominated by deeply weathered clay (Robinson, 1991; Benson, et al. 1996; Tozer, 2003).

The woodlands of this area are floristically distinct, and reflect a gradient of soil types (James, 1997; French et al., 2000). The better-drained areas are dominated by two tree species: *Eucalyptus moluccana* and *Eucalyptus tereticornis*. In marshy depressions *Eucalyptus amplifolia*, *Melaleuca decora* and other paperbarks are generally the dominant species. Ironbarks (e.g. *Eucalyptus fibrosa*) are abundant in many places, especially in drier zones. Along the rich alluvial flats of the Hawkesbury-Nepean River, *Angophora subvelutina, Eucalyptus deanei, Eucalyptus pilularis* and *Angophora floribunda* grow. The creek lines are dotted by *Casuarina*
Shrubs, such as the opportunistic *Bursaria spinosa* and *Acacia parramattenis*, are found throughout the area and form part of the understorey vegetation. Many of the native grasses have been lost and have been replaced by introduced species and these are now the main ground cover plants (Benson & Howell, 1990; Robinson 1991; James 1997).

![Map highlighting the Cumberland Plain region. The inset map indicates its location in relation to Sydney, NSW (Benson, et al. 1996).](image)

**Figure 2.1.** Map highlighting the Cumberland Plain region. The inset map indicates its location in relation to Sydney, NSW (Benson, et al. 1996).

From the earliest records of European settlement, agricultural activities have been important in this region. As a result of the associated extensive clearing, much of the
native landscape has been replaced with grazing land and crop production. More recent history has resulted in these areas and much of the remaining indigenous woodlands being supplanted by urban sprawl (Benson & Howell 1990; James 1997). By 1990 these impacts had resulted in the loss of all except 6,420 ha (or less than 6%) of 107,000 ha of the original vegetation remained (Benson & Howell, 1990). Erosion of the remaining woodlands has continued since that time (Tozer, 2003). Areas of intact forest that remain are patchy or isolated stands of both woodland and open-forest formations (Robinson 1991; Benson 1992; Benson, et al. 1996).

These remnant areas are usually small (often <10ha) and irregular in shape and thus susceptible to edge impacts. Almost all of the remaining stands are degraded by over-grazing, altered water regimes, habitat loss, fragmentation, pollution, rubbish dumping, weed and feral animal infestation (James 1997; Benson 1997). With only 0.15% of Cumberland bushland protected in conservation reserves, anthropogenic impacts continue to threaten its survival (Anon, 1999). As a result the Cumberland Plain community has been identified as an Endangered Ecosystem under both state (NSW Threatened Species Conservation Act 1995) and federal (Environment Protection and Biodiversity Conservation Act 1999) legislation (Environment Australia, 2001; Tozer, 2003). A recovery plan is being prepared by the New South Wales Government, while Federal funding has been made available for regeneration work (Department of Environment & Conservation (NSW), 2005).

2.1.2. Study Site - Hawkesbury.

The Hawkesbury region, a part of this Cumberland Plain, is located north-west of Sydney. The climate in the area varies between cold, dry winters (highest rainfall
99mm; average annual temperature 10.4°C to hot, wet summers (highest rainfall 801.3 mm; average annual temperature 23.9°C; Bureau of Metrology 2004).

An indication of the historic significance of the area for agriculture is that the Hawkesbury Agricultural College (Richmond) was established in 1891 (Benson, 1997), now the University of Western Sydney. Residential development has concentrated around the towns of Windsor and Richmond. However, outlying areas have become popular as Sydney’s land shortage forces people further out from the Central Business District (James 1997) and this has exacerbated the anthropogenic impacts within the area.

Although there are approximately 3000 ha of remnant bushland in the Hawkesbury region, most of these remnants are in the less fertile and steeper areas of the sandstone plateaux. Some of the most significant of these remnants of these woodlands surround the University of Western Sydney, Richmond (150°75'E, 33°62'S, elevation 20 m). The majority of this is part of a heritage reserve (James 1997), and the sites utilised in this study were drawn from these remnants.

2.1.3. Remnant description and selection.

This study spanned seven remnant woodlands that ranged in size from 20 to 176 ha (Figure 2.2). The largest remnant was divided by a number of fence lines and was treated as two separate remnants. They all contained *Eucalyptus* and *Melaleuca* forests interspersed with exotic weeds, such as Blackberry (*Rubus* spp.), *Lantana* spp. and Kikuyu grass (*Pennisetum* sp.). They were bounded by agriculture,
easements and/or roadways. Although the time of initial fragmentation is unknown, current land use practices have been in place for 20 - 110 years, while fire has been excluded for over thirty years (Burgin, pers. com.).

Four perimeter (characterised by woodland meeting grassed paddocks) sites (1 - 4) in remnants of 20 - 56 ha and four interior sites (5 - 8) in remnants of 52 - 88 ha were randomly selected from among available remnants on the campus (Plate 2.1 to 2.4). All sites were affected by traffic and aircraft noise.

Kremaster and Bunnell (1999) determined that species distribution is most influenced within 50 m of the edge. Therefore, edge sampling was conducted within 10 m of the outer wooded perimeter and core sampling was conducted ≥150 m from the edge.

Fieldwork was conducted between summer 2000 and autumn 2002. During this time the climate of the area varied from hot dry weather in late spring and early summer to cool wet weather during late summer, early autumn (Figures 2.3 and 2.4). Average rainfall for the study time was 103.21mm, with unseasonably high rainfall during February 2002 (mean = 274.5mm). Between mid-December 2001 and early January 2002 bushfires eclipsed the area. The average ambient air temperature over the sampling period was 21.11°C.
Inset shows the study site in relation to Sydney, NSW
Plate 2.1. Edge Site 1. This site is characterised by the presence of powerlines.

Plate 2.2. Edge Site 2. This picture epitomise the edge sites, i.e. grassland meeting bushland.
Plate 2.3. Core Site 6 showing *Melaleuca spp.* Forest.

Plate 2.4. Core Site 7 showing *Eucalypt spp.* Forest.
Figure 2.3. Average monthly ambient temperature (°C) for the study period, recorded at the Hawkesbury campus of University of Western Sydney (● - 1998, ● - 1999, ▲ - 2000, ● - 2001, ● - 2002).

Figure 2.4. Average monthly rainfall (mm) for the study period, recorded at the Hawkesbury campus of University of Western Sydney (● - 1998, ● - 1999, ● - 2000, ● - 2001, ● - 2002).
Chapter 3. Edge Effects on Community Diversity.

3.1. Introduction.

The impacts of forest clearance in Australia have long been the subject of debate (Lunney, 2004). As a result of clearance rates of 400,000 to 500,000 hectares per year (Possingham, 2003), habitat loss, degradation and fragmentation have had detrimental effects on species diversity (Fox, 1990; Possingham, 1996). Of particular concern has been the introduction of modified environments that abut native remnants; their influence on ecological functioning, particularly across the edge: and the long term these impacts may have on species survival and dispersal (Fox, 1990; Recher, 1996, 1999).

The survival of a species in fragmented areas and their edges, often depends on the size, configuration and age of the remnant being examined (Rankmore & Price, 2004). For example, remnant area will often regulate the size and composition of the local biological community. It is, therefore, desirable to understand the impacts that fragmentation and edges have on a species, the overall biological community response to these areas, and how taxa interact with the altered environment and interact.

Community studies in remnants are not uncommon (both in Australia and overseas) although most have such has tended to be restricted to a single taxonomic group, such as plants (Chiarello, 1999; Didham & Lawton, 1999), arthropods (Dangerfield...
et al., 2003; Dauber & Wolters, 2004), amphibians (Toral et al., 2002; Gray et al., 2004), reptiles (Conroy, 1999; Mac Nally & Brown, 2001), avian (Arnold, 2003; Castelletta et al., 2005) and mammals (Downes et al., 1997; Chiarello, 1999), and their response to edge and other fragmentation effects. There have been relatively few studies that have investigated patterns of community response (Hawkins et al., 1990). The exceptions have demonstrated that, while response to fragmentation by individual groups within the community may vary, the community as a whole is altered throughout the remnant, in both diversity and abundance (e.g. Andrén, 1994; Fabricius et al., 2003; Scott et al., 2006).

Most ecological community research has concentrated on the effects of fragmentation on abundance and diversity by comparing overall remnant species assemblage to intact systems (e.g. Smith et al., 1996; Abensperg-Traun & Steven, 1997; Catterall et al., 2001). There has been a dearth of information on the effects edges may have on overall community composition and taxa numbers.

Edges are recognised as the junction where two or more ecosystems are connected, and the effects generated from that can be abiotic, such as changes to air flow, temperature, humidity and soil moisture (Reese & Ratti, 1988; Freidenburg, 1998); or biological, such as changes to abundance, diversity, and species dispersal (Yahner, 1988; Laurance & Yensen, 1991). As such edges are considered to be harsh environments where those species that adjust to the altered environment the fastest survive (Murcia, 1995).
The detrimental effects edges have on survival of individual taxonomic groups have been well documented. Studies on a specific taxon, such as arthropods (Dangerfield et al., 2003), birds (Berry, 2001) and skinks (Anderson & Burgin, 2002), have demonstrated that species richness and abundance in perimeter areas can differ from those encountered in the core of a remnant. Each of these groups mentioned here have been considered ‘excellent’ biological indicators that can supply valuable information about the health of an ecosystem (Raxworthy & Nussbaum, 1994; Andersen et al., 2004; Watson et al., 2004). However, there is an absence of information about the effects these groups may experience as part of a community in edge and core areas and how that, in turn, may affect their interaction within remnants.

Previously, Anderson and Burgin (2002) estimated that the number of small skinks occupying edge areas in remnant Cumberland Plain woodland (Australia) was low compared to the interior habitat. This occurred despite the availability of equivalent habitat for skinks in edge and core areas. However, they did not examine whether the dynamics of other taxa within the community. Both birds and arthropods interact with skinks as predators, prey and/or competitors, and the study of these components of the community may supply a stronger indication of the health of an ecosystem than the study of a single components.

The following questions are investigated in this chapter:
Does the species richness and abundance of one species parallel the dynamics of others species of the community (i.e. arthropods, small skinks and avian) in different habitats (i.e. edge and core areas of remnant woodland)?

Does the overall interspecific community composition vary between edge and core?

Could the pattern of distribution affect the interaction among these groups?

### 3.2. Methods

Selection of sites is presented in Chapter 2.

#### 3.2.1. Skink Sampling

Skink sampling was conducted over three sampling periods (autumn, spring 2001, and summer 2002) at four week intervals. Sites were sampled at the rate of two per day (i.e. one edge and one core site arbitrarily paired), with sampling completed within four consecutive days (with some adjustment when there were adverse weather conditions).

Reptiles were counted mid-morning, when skinks are actively foraging, utilising point of transect surveying techniques (*cf.* Buckland *et al.*, 1993). This method was chosen over the more commonly used pitfall trap method (e.g. Jardine, 1998; Jelbart, 1998; Singh *et al.*, 2002) because past experience (Anderson & Burgin, 2002) had
shown that pit-fall trapping in the habitat sampled was time consuming to set up, and yielded relatively fewer animals than point of transect survey.

Transects of approximately 20m long, with points every 5m, were randomly laid out within the study area. To count skinks, the researcher walked slowly from point to point, taking precautions to minimise noise. At each point the researcher crouched for 5 minutes to observe the area immediately in front and at either side. Skinks observed were identified and numbers recorded.

The point of transect method of sampling, while generally more fruitful than trapping, does have some limitations. The most restrictive of these is that sampling is impacted by the researchers line of vision (Buckland et al., 1993). To ensure accuracy of identification the researcher stood on a point of transect, while a second researcher placed a ‘model’ skink (created as per section 7.2.3) at varying distances from the original point. This continued until details of the model could no longer be ascertained. A tape measure was then used to measure the length of the ‘field of view’. In this study accuracy of identification (particularly in the Lampropholis species) was compromised after approximately 1.65m, therefore animals beyond that distance were not included.

3.2.2. Bird Sampling

Diurnal bird sampling is traditionally conducted in the early morning as the birds leave their roosting sites (Pizzey & Knight, 1997); however, in this study sampling was conducted mid-morning. This allowed bird data to be collected when skinks
were first emerging and beginning to bask and, presumably, more likely to attract predators.

Sampling was conducted as with skink sampling (see Chapter 3.2.1), with some variation. Transect lines were extended to 50m with points 10m apart. Altered transect distance was implemented to accommodate the variation in animal size and habitat use. Taxon identification was achieved utilising both visual contact (verified with Pizarzey & Knight 1997), and call recognition. The species numbers, and the number within each species, were recorded.

Published literature (e.g. Piper & Catterall, 2003) indicated that avian distribution throughout remnants was based on size of the individual birds. Therefore, the bird species encountered in this study were further assessed based on body size. The parameters used (large, medium and small) were based on the work presented by Pizzey and Knight (1997).

3.2.3. Arthropod sampling

At all sites, arthropod sampling was initially undertaken in late summer through autumn (2001). A combination of pitfall trapping and sweep netting was used. The use of the twin methods ensured that both terrestrial and aerial invertebrates were collected, as both have been reported to be prey items of small skinks (Crome, 1981; Webb, 1983; Lunney et al., 1989; Warner, 1995).
Sampling was again undertaken during four weeks in spring 2001 and summer 2002 and in two weeks in autumn 2002. Sampling via sweep netting was conducted once a week (again with some alteration of precise days when there were adverse weather conditions). Sampling usually commenced late morning, a time when small skinks were likely to be actively foraging. Pitfall traps were opened for seven days each month (regardless of weather conditions).

To sample aerial species two 20m long transects were randomly established each sampling day. A hand net (approximately 30cm in diameter and 90cm deep), sprayed with commercial insect spray (Black and Gold™ Surface Spray, Parramatta, Australia), was used to sweep the undergrowth. The researcher walked each transect, sweeping approximately 30cm above the ground, and 1m wide of their body. At each site, once the contents of the sweep net were euthanized (by respraying with the insecticide); they were placed into a glass jar and covered with 70% ethanol.

At each site, the location of the pitfall traps was located parallel, but separate, from these pitfall transects. Six pitfall traps, consisting of white plastic drinking cups, were sunk into the ground approximately 40cm apart, to the depth of the rim of the cup. They were filled to a depth of 5cm with 30% glycol to preserve invertebrates that feel into the trap. After seven days they were cleared and the specimens were placed in individual glass jars (one per trap) and preserved similarly to the sweep net collection. After clearing, the traps were reset each day of the study, in a new location.
In the laboratory invertebrates were identified to order (cf. New, 1996; Dahms et al., 1997; Zborowski & Storey, 1998) using an Olympus SZX 9 enhanced with a fiberoptic illuminator. All specimens collected were used in this study, including the pitfall traps by-catch of aquatic species, such as Diptera (mosquito) larva. It was considered that given the right conditions these insects viewed the remnants as suitable habitat. Therefore, they should be included in this study of arthropod assemblage.

3.2.4. Analysis of Data.

All replicates at both sites were used in all analysis except where identified (either in this or subsequent chapters).

All taxa encountered within this study were analysed using multivariate techniques within PRIMER, Version 5 (2001). The method was chosen because this analysis does not require species to be present in similar numbers across sites and, therefore, eliminates many right skewed problems associated with such skewness (Clark et al., 2005).

Since the techniques used required that the data show homogeneity of variances, a pre-analysis of data was undertaken using the multiple dimensional scaling stress tests. When the data were not homogeneous, transformation was achieved using square root, $^{4\sqrt{\cdot}}$ or Log (as appropriate) and the data were retested to maximise the fit with this assumption of homogeneity.
Similarity between sites was calculated using Bray-Curtis similarity coefficient. Multiple Dimension Scale (MDS) analysis was then used to visualise the arrangement of similar groups. The one-way ANOSIM permutation test was used to assess the similarity or differences between sites sampled at the edge compared to those sampled in the core (Clarke & Warwick, 2001).

Student t-tests were conducted using Statistica, Version 5.5 (1999) to determine variation of taxa means between core and edge. However, where insufficient data were available (i.e. where < 3 individuals of any taxon were encountered) the data were considered not amenable to analysis, and no test was conducted. Before undertaking t-test analysis homogeneity of variances was validated using Cochran’s C Test, and when transformation was required, this was achieved using a square root.

In addition, dominance differences, between core and edge, were calculated using rank-abundance curves. These curves are used in preference of diversity indices because no data is lost. They are calculated using the logged abundance (to ensure data were not homogeneous) for each individual taxonomic group and assigned a relative rank (as per Hoyle, 2005; Hoyle & Harborne, 2005). However, where a species recorded a zero value in either the core or the edge, they were not graphed, but their ranking recorded within the adjoining table.

The shape of the rank-abundance curves were compared to a linear rank or trend line. This allowed for an evaluation of expected abundance of each species against what was observed. The slopes of the trend lines were calculated to determine how well
these distributions matched the log series. As no significant differences were observed than no further analysis was conducted.

Graphs and tables were generated utilising either Statistica, Version 5.5 (1999), Microsoft Excel 2000 or Word 2000, as convenient.

3.3. Results.

3.3.1. Arthropod Abundance and Diversity.

A total of 3,232 arthropods, representing 22 taxa (1,792 edge, 1,440 core) were collected (Figure 3.1). Overall, edge sites displayed a greater similarity as a group (average 71.2%) than core sites (66.5%), and arthropod communities were similar between the core and the edge of remnants (R = 0.094, \( P = 0.286 \); Figure 3.2), although abundance differed between assemblages.

The rank-order (Figure 3.3) showed the species numbers differed between edge and core. Ants (sub-set of Hymenoptera) were most abundant on edges, while spiders (sub-set of Arena) were in greatest abundance in core habitats. Of these, only ant abundance was significantly different between the edge and core areas (\( P > 0.023 \); Table 3.1).

The rank abundance curve indicted that three groups, Acari, Lepidoptera and lepidopteran larvae, deviated from the trend line (Figure 3.3.), although their abundance across the habitats did not differ significantly (Table 3.1).

42
Figure 3.1. Number of arthropods encountered across all edge (■) and core (○) sites of woodland remnants in peri-urban north-western Sydney, autumn 2001.
Figure 3.2. MDS plots (derived from Bray-Curtis similarity) based on arthropod abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed the greatest degree of similarity as a group (average 71.15%). Core sites were less similar than edge sites (average 66.47%). There was a significant similarity between edge and core sites ($R = 0.094$, $P = 0.29$).

Table 3.1. Mean number, standard deviation and level of significance (* donates significance at 0.05) of the total number of arthropods encountered across all the edge and core sites sampled in woodland remnants in peri-urban north-western Sydney. Included in table is species habitat niche as either terrestrial (T), aerial/arboreal (A) or aquatic (W).

<table>
<thead>
<tr>
<th>Class</th>
<th>Order</th>
<th>Niche</th>
<th>Edge Mean</th>
<th>S.D.</th>
<th>Core Mean</th>
<th>S.D.</th>
<th>T Value (d.f. 6)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arachnida</td>
<td>Acari</td>
<td>T</td>
<td>7.8</td>
<td>11.70</td>
<td>1.8</td>
<td>0.50</td>
<td>1.025</td>
<td>0.345</td>
</tr>
<tr>
<td></td>
<td>Araneae</td>
<td>T/A</td>
<td>79.0</td>
<td>21.71</td>
<td>71.3</td>
<td>27.83</td>
<td>0.439</td>
<td>0.676</td>
</tr>
<tr>
<td>Myriapoda</td>
<td>Chilopoda</td>
<td>T/A</td>
<td>0.3</td>
<td>0.50</td>
<td>0.3</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diplodopa</td>
<td>T/A</td>
<td>2.8</td>
<td>2.22</td>
<td>1.36</td>
<td>0.96</td>
<td>1.242</td>
<td>0.261</td>
</tr>
<tr>
<td>Crustacea</td>
<td>Isopoda</td>
<td>T</td>
<td>0.5</td>
<td>0.58</td>
<td>1.5</td>
<td>3.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collembola</td>
<td></td>
<td>T</td>
<td>61.5</td>
<td>42.46</td>
<td>57.8</td>
<td>45.14</td>
<td>0.121</td>
<td>0.908</td>
</tr>
<tr>
<td>Diplopoidea</td>
<td></td>
<td>T</td>
<td>2.8</td>
<td>1.26</td>
<td>1.3</td>
<td>1.89</td>
<td>1.320</td>
<td>0.235</td>
</tr>
<tr>
<td>Insecta</td>
<td>Blattodea</td>
<td>T/A</td>
<td>2.0</td>
<td>0.82</td>
<td>0.5</td>
<td>0.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coleoptera</td>
<td>T/A</td>
<td>22.5</td>
<td>18.23</td>
<td>26.5</td>
<td>16.52</td>
<td>0.256</td>
<td>0.756</td>
</tr>
<tr>
<td></td>
<td>Coleoptera Larva</td>
<td>T</td>
<td>3.3</td>
<td>1.71</td>
<td>3.8</td>
<td>3.59</td>
<td>0.251</td>
<td>0.810</td>
</tr>
<tr>
<td></td>
<td>Diptera</td>
<td>A</td>
<td>77.5</td>
<td>22.49</td>
<td>64.5</td>
<td>36.10</td>
<td>0.611</td>
<td>0.563</td>
</tr>
<tr>
<td></td>
<td>Diptera Larva</td>
<td>T/W</td>
<td>14.0</td>
<td>28.00</td>
<td>1.3</td>
<td>1.50</td>
<td>0.909</td>
<td>0.398</td>
</tr>
<tr>
<td></td>
<td>Embioptera</td>
<td>T/A</td>
<td>0.0</td>
<td>0.00</td>
<td>1.0</td>
<td>1.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hemiptera</td>
<td>A</td>
<td>24.3</td>
<td>7.37</td>
<td>28.5</td>
<td>15.07</td>
<td>0.507</td>
<td>0.630</td>
</tr>
<tr>
<td>Hymenoptera ants</td>
<td></td>
<td>T</td>
<td>118.8</td>
<td>41.63</td>
<td>52.5</td>
<td>11.96</td>
<td>3.059</td>
<td>0.022*</td>
</tr>
<tr>
<td>Hymenoptera other</td>
<td></td>
<td>A</td>
<td>2.3</td>
<td>0.957</td>
<td>1.0</td>
<td>0.00</td>
<td>2.611</td>
<td>0.040*</td>
</tr>
<tr>
<td>Isoptera</td>
<td>T</td>
<td>0.0</td>
<td>0.00</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>A</td>
<td>4.8</td>
<td>1.71</td>
<td>6.3</td>
<td>4.35</td>
<td>0.642</td>
<td>0.544</td>
<td></td>
</tr>
<tr>
<td>Lepidoptera Larva</td>
<td></td>
<td>A</td>
<td>7.8</td>
<td>5.62</td>
<td>27.0</td>
<td>21.21</td>
<td>1.754</td>
<td>0.130</td>
</tr>
<tr>
<td>Mantodea</td>
<td>T</td>
<td>1.0</td>
<td>1.41</td>
<td>1.3</td>
<td>0.96</td>
<td>0.293</td>
<td>0.779</td>
<td></td>
</tr>
<tr>
<td>Neuroptera</td>
<td>T</td>
<td>0.8</td>
<td>0.96</td>
<td>0.8</td>
<td>0.96</td>
<td>0.00</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>A</td>
<td>0.5</td>
<td>0.58</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthoptera</td>
<td>T</td>
<td>11.8</td>
<td>11.59</td>
<td>8.8</td>
<td>6.80</td>
<td>0.447</td>
<td>0.671</td>
<td></td>
</tr>
<tr>
<td>Phasmatodea</td>
<td>T</td>
<td>1.8</td>
<td>1.50</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pscoptera</td>
<td>T</td>
<td>2.0</td>
<td>4.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thysanura</td>
<td>T</td>
<td>2.0</td>
<td>0.50</td>
<td>0.5</td>
<td>0.58</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.3. Rank abundance curves (and corresponding arthropod species) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001. Plotted lines are linear trend-lines (edge, $R^2 = 0.97$; core, $R^2 = 0.91$).
3.3.2. Skink Abundance and Diversity.

A total of 486 skinks from four species (*Lampropholis guichenoti, Lampropholis delicata, Cryptoblepharus virgatus* and *Saproscincus mustelina*), 352 on core sites and 134 on edge sites, were encountered (Figure 3.4). Two species (*L. delicata, L. guichenoti*) made up 95% of the abundance.

Distribution of species in the edge and core areas was clearly different. There was no similarity in skink population between the two habitats ($R = 0.635, P = 0.029$). The $R$ value of 0.635 indicated that skink numbers within sites had a greater similarity than those between edge and core. Core sites were more similar (group average 91.1%) than edge sites (71.8%). Two core sites (5 and 6) were identical in abundance and diversity, and as such they display one on top of the other in the MDS plot (Figure 3.5).

Rank order was consistent between core and edge areas (Figure 3.6), with *L. guichenoti* most abundant in both habitats and *S. mustelina* the least frequently encountered skink species. However, both *L. guichenoti* ($P > 0.0001$) and *L. delicata* ($P > 0.0016$) displayed a significant difference between the two habitat types (Table 3.2).
Table 3.2. Mean number, standard deviation and level of significance (* donates significance at 0.01; (** donates significance at 0.001) of the total number of skinks encountered across all the edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, during autumn, spring 2001, and summer 2002.

<table>
<thead>
<tr>
<th>Species</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T Value (d.f. 6)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lampropholis guichenoti</td>
<td>19.5</td>
<td>9.61</td>
<td>64.5</td>
<td>2.89</td>
<td>8.97</td>
<td>0.0001**</td>
</tr>
<tr>
<td>L. delicata</td>
<td>10.3</td>
<td>1.71</td>
<td>21.8</td>
<td>3.86</td>
<td>5.446</td>
<td>0.002*</td>
</tr>
<tr>
<td>Cryptoblepharus virgatus</td>
<td>3.3</td>
<td>6.50</td>
<td>1.5</td>
<td>1.91</td>
<td>0.517</td>
<td>0.624</td>
</tr>
<tr>
<td>Saproscincus mustelina</td>
<td>0.5</td>
<td>1.00</td>
<td>0.3</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.4. Total number of individual skinks and species observed across edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, 2001/02.
Figure 3.5. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Core sites displayed the greatest degree of similarity as a group (average 91.1%). Edge sites were less similar than core sites (average 71.8%). There is no significant similarity between edge and core sites ($R = 0.635, P = 0.029$).
Figure 3.6. Rank abundance curves (and corresponding skink species) in edge (■) and core (△) of woodland remnants in peri-urban north-western Sydney, during autumn, spring 2001, and summer 2002. Plotted lines are linear trend-lines (edge, $R^2 = 0.98$; core, $R^2 = 0.95$).
3.3.3. *Avian Abundance and Diversity.*

A total of 872 individuals, representing 26 bird species (524 edge, 348 core) were encountered, of which three species were introduced (Figure 3.7; Table 3.3). The avian communities were dissimilar between the edge and the core sites ($R = 0.94, P = 0.029$; Figure 3.8), and the proportion of taxa differed between assemblages. Bird size also appeared to be a delineating factor. Large to medium-sized birds were generally encountered in higher numbers in edge areas, compared to core. In contrast smaller birds were only observed in core areas. Differentiation of habitat use based on size often equated with some species only being observed in one habitat. For example, *Ardea ibis, Threskiornis molucca, Platycercus eximinus* among others, were only observed in the edge. In contrast bird species such as *Cormobates leucophaeus, Acanthiza pyusilla* and *Philemon corniculatus* were only observed in core areas (Table 3.3).

Overall, edge sites displayed a slightly greater degree of similarity as a group (average 58.9%), than core sites (58.4%), although the similarity in both was moderate.

Not all species were observed on all sites or in both habitats and, therefore, the order of ranking was not consistent between the habitat types, but was consistent with the trend-line (Figure 3.9). In edge areas *Manorina melanocephala*, noisy miner was the most abundant species. While in core areas *Neochmia temporalis*, red-browed finch was the most abundant. However, only two species, *M. melanocephala* ($P > 0.006$)
and *Cracticus torquatus* (*P > 0.009*) were significantly different between the edge and core areas (Table 3.3).
Table 3.3. Mean number, standard deviation and level of significance (* donates significance at 0.01) of the total number of birds encountered across all the edge and core sites sampled in woodland remnants in peri-urban north-western Sydney. Included in table is species size: Large (L; >40cm), Medium (M; 20 – 40cm) and Small (S; <20cm), as well as whether they are endemic (E) or introduced (I).

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Size</th>
<th>E/I</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T Value  (d.f. 6)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ardeidae</td>
<td><em>Ardea ibis</em></td>
<td>L I</td>
<td>3.3</td>
<td>5.25</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threskiornithidae</td>
<td><em>Threskiornis molucca</em></td>
<td>L E</td>
<td>20.0</td>
<td>28.28</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columbidae</td>
<td><em>Ocyphaps lophotes</em></td>
<td>M E</td>
<td>8.3</td>
<td>10.90</td>
<td>0.3</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Geopelia striata</em></td>
<td>S E</td>
<td>0.0</td>
<td>0.00</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cacatuidae</td>
<td><em>Calyporhynchus funereus</em></td>
<td>L E</td>
<td>0.5</td>
<td>1.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Cacatuna roseicapilla</em></td>
<td>M E</td>
<td>5.0</td>
<td>4.97</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>C. galerita</em></td>
<td>L E</td>
<td>3.0</td>
<td>4.76</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psittacidae</td>
<td><em>Platycercus eximius</em></td>
<td>M E</td>
<td>3.0</td>
<td>3.83</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halcyonidae</td>
<td><em>Dacelo novaeguineae</em></td>
<td>L E</td>
<td>4.3</td>
<td>5.32</td>
<td>3.0</td>
<td>3.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climacteridae</td>
<td><em>Cormobates leucophaeus</em></td>
<td>S E</td>
<td>0.0</td>
<td>0.00</td>
<td>0.3</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pardalotidae</td>
<td><em>Acanthiza pyuilla</em></td>
<td>S E</td>
<td>0.0</td>
<td>0.00</td>
<td>1.5</td>
<td>1.91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meliphagidae</td>
<td><em>Philemon corniculatus</em></td>
<td>M E</td>
<td>0.0</td>
<td>0.00</td>
<td>3.8</td>
<td>7.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Manorina melanocephala</em></td>
<td>M E</td>
<td>25.3</td>
<td>7.37</td>
<td>5.3</td>
<td>6.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicuridae</td>
<td><em>Grallina cyanoleuca</em></td>
<td>M E</td>
<td>1.0</td>
<td>2.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Rhipidura fuliginosa</em></td>
<td>S E</td>
<td>0.0</td>
<td>0.00</td>
<td>2.3</td>
<td>0.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>R. rufifrons</em></td>
<td>S E</td>
<td>0.0</td>
<td>0.00</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>R. leucophrys</em></td>
<td>S E</td>
<td>0.0</td>
<td>1.00</td>
<td>3.0</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campephagidae</td>
<td><em>Coracina novaehollandiae</em></td>
<td>M E</td>
<td>1.8</td>
<td>2.06</td>
<td>4.0</td>
<td>3.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artamidae</td>
<td><em>Cracticus torquatus</em></td>
<td>M E</td>
<td>8.5</td>
<td>3.70</td>
<td>1.3</td>
<td>0.96</td>
<td></td>
<td>3.797</td>
<td>0.009*</td>
</tr>
<tr>
<td></td>
<td><em>Gymnorhina tibicen</em></td>
<td>L E</td>
<td>10.8</td>
<td>8.18</td>
<td>2.3</td>
<td>2.63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corvidae</td>
<td><em>Corvus corone</em></td>
<td>L E</td>
<td>14.5</td>
<td>11.09</td>
<td>7.5</td>
<td>1.91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cororacidae</td>
<td><em>Corcorax melanorhamphos</em></td>
<td>L E</td>
<td>14.0</td>
<td>15.10</td>
<td>14.3</td>
<td>6.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fringillidae</td>
<td><em>Neochmia temporalis</em></td>
<td>S E</td>
<td>0.0</td>
<td>0.00</td>
<td>14.5</td>
<td>25.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hirundinidae</td>
<td><em>Hirundo nigricans</em></td>
<td>S E</td>
<td>0.0</td>
<td>0.00</td>
<td>12.5</td>
<td>6.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sturnidae</td>
<td><em>Acridotheres tristis</em></td>
<td>M I</td>
<td>7.0</td>
<td>3.16</td>
<td>10.0</td>
<td>10.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Sturnus vulgaris</em></td>
<td>M I</td>
<td>1.0</td>
<td>2.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.7 Avian abundance and diversity across edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney.
Figure 3.8. Rank abundance curves (and corresponding avian species) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney. Plotted lines are linear trend-lines (edge, \( R^2 = 0.98 \); core, \( R^2 = 0.98 \)).
Figure 3.9. MDS plots (derived from Bray-Curtis similarity) based on avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed greatest similarity as a group (average 58.9%). Core sites were slightly less similar than edges (average 58.4%). The site types are well separated ($R = 0.94, P = 0.029$).

3.3.4. Community Structure.

A total of 26 bird and 4 skink species, together with 22 arthropod orders, were identified across the remnants; 10 avian, 4 skink and 17 arthropod taxa were common to both edge and core areas (Figure 3.10). Of these taxonomic groups, only skinks were significantly different between the core and edge habitats ($P < 0.0006$).

There was differences in community assemblage between edge and core sites ($R = 0.969, P = 0.029$). Edge and core sites displayed greater similarity within their habitat grouping (edges 58.9% and core 58.9%; Figure 3.11) than between them.
Figure 3.10. Number of individuals within each taxonomic group, encountered across edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, during 2001 and 2002.

Figure 3.11 MDS plots (derived from Bray-Curtis similarity) based on the overall community (of arthropod, skink and avian) abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Sites were equivalently similar (edge average 58.9%; core average 58.9%). There was no significant similarity between edge and core sites ($R = 0.969$, $P = 0.029$).
3.4. Discussion.

3.4.1. Arthropod Abundance and Diversity

The lack of difference in arthropod diversity between the edge and core habitats in the Cumberland Plain woodland remnants studied was not consistent with some previous studies conducted on arthropods in edge areas. For example, in the naturally formed edges of the Sturt National Park in north western New South Wales (Australia), arthropod diversity showed clinal change from the interior to perimeter areas (Dangerfield et al., 2003). However, where edges were artificially increased and disturbance was more intense, more dramatic shifts in community structure can occur between the edge and core (Gibb & Hochuli, 2002).

Based on the results of such arthropod diversity studies in remnant edge and core habitats, it was expected that diversity would have changed spatially in the study sites. This assumption has been supported by previous research that showed that in edges abutting areas exposed to detrimental land use practices (e.g. logging, hazard reduction and agricultural practices), the impacts result in species loss (e.g. Lunney & Ashby, 1987). For example, nocturnal insect diversity was examined across farm areas utilising different agricultural practices (i.e. organic versus conventional) in the United Kingdom. The researchers demonstrated that the use of agrochemical practices consistently resulted in a reduction in insect diversity, compared to organic farms (Wickramasinghe et al., 2004). Remnants that abutted farms using pesticides may also experience a reduction in diversity due to chemical drift, and/or reduced recruitment opportunity (Hester & Hobbs, 1992; Ashley & Robinson, 1996).
Although the edges created within the areas under study were initially formed due to agricultural purposes, they have essentially ceased to be utilised in that capacity (except for sporadic use for stock agistment) for at least twenty years. Any influence of agrochemicals that were used in the past would have been diluted over time, particularly in the interior areas. Since the diversity in edge and core of the remnants was similar, any impact had either been diminished over time, or had impacted arthropod diversity equally across the remnants.

These areas have also not been exposed to burn off for hazard reduction or logging beyond the initial remnant creation (White & Burgin, 2004). These remnants are also effectively free of other forms of human-induced disturbance (e.g. trampling) in the areas immediately adjacent to the edge or within the remnants. Overall, these areas have been effectively left to natural processes for decades and this could have provided time for arthropod diversity to reach equilibrium throughout the remnant. The alternative is that the impact was such that it continued to impact on the arthropod diversity across the remnants. However, the former scenario is more likely since there is evidence to suggest that arthropod’s ability to recolonise and increase diversity is dependent on whether disturbance events are prolonged. For example, initial logging of boreal peatland forests in Canada, generated a loss of aerial arthropod diversity. When disturbance within those areas ceased, diversity steadily increased over a period of 2.5 to 3 years, however, in areas where thinning persisted, diversity continued to decline (Deans et al., 2005).

Another factor that may have influenced arthropod diversity in the study sites was habitat quality. This can alter diversity when the habitat is not maintained
throughout the remnant. This has been demonstrated in findings of studies conducted on arthropods communities in habitat fragments of moss in the United Kingdom (Hoyle & Harborne, 2005), woodlands in Western Australia (Abensperg-Traun & Smith, 1999), and orchard meadows in Germany (Steffan-Dewenter, 2003). In each of these studies, the authors suggested that the major causative factor of changed diversity between interior and perimeter of remnants appeared to be a lack of adequate habitat resources (e.g. breeding and sheltering sites) available in edge areas.

While the remnants studied were not ‘pristine’ in terms of vegetation structure, and therefore habitat has been altered, habitat may be equivalent throughout the remnant. Anderson and Burgin (2001) examined these sites for appropriate skink habitat, and the variables measured could also be equated to arthropod requirements (e.g. litter depth, canopy cover, ground cover percentage; Tscharntke et al., 2002). They concluded that both edge and core habitats were equivalent with respect to required habitat components for small skinks. It could therefore be expected that the overall arthropod diversity between edge and core would be similar.

Arthropod diversity across core and edge habitats could also be linked to the size of the remnants. These remnants are small (<200ha) and there is evidence to suggest that, in remnants size, can have significant effect on species diversity. For example, in heathland remnants within Sydney, researchers demonstrated that smaller fragments displayed greater similarity arthropod diversity throughout than in larger remnants (Gibb & Hochuli, 2002). Comparable results have been reported on
arthropod diversity in chalk grassland fragments of Germany (Tscharntke et al., 2002).

Although diversity within a specific group may show similarity between edge and core areas of remnants, the abundance of taxa within the group may vary considerably from species to species. For example, Hansson (2002) examined mammalian abundance between perimeter and interior areas of coniferous forest fragments. He determined that while roe deer numbers decreased in edge areas, brown hares (Lepus capensis), squirrels (Tamiasciurus sp.), voles (Microtus sp.) and other granivorous mammals, increased in number in edges compared to core areas. Similarly a study conducted on fauna inhabiting fragmented seagrass meadows indicated that while crustaceans generally occupied edge areas in greater abundance than interior zones, polychaetes and bivalves distribution were reversed (Tanner, 2005).

Previous research has indicated that even within a single taxon, edge response can differ among species and this was shown in the current study: ant abundance was significantly greater in edges, than in core areas. This pattern of variation has also been shown in forest remnants of Madagascar where lemur species did not respond to edge habitat in similar ways. Of the six species encountered, only two, Microbeus rufus and Propithecus diadema edwardsi, consistently maintained larger numbers within the perimeter of the remnant than in the interior (Lehman et al., 2006). The authors suggested that these two species were adapted to edge life, due to the increased variety of food found in these areas.
Variation in abundance of arthropod species has also been shown to vary among vegetation types. For example, Bolger *et al.*, 1998) conducted a study on arthropod abundance in various fragmented coastal scrublands in Southern California. They concluded that both ant (Hymenoptera) and roaches (Blattodea) numbers were in greater abundance in perimeter areas compared to the interior of the scrub, particularly in older, smaller remnants. This pattern was observed to occur in the current study, although roaches demonstrated no statically significant variation between edge and core. In contrast, bees and wasps (also Hymenoptera) were not found in substantial numbers in edge areas compared to the core areas in calcareous grasslands in Germany (Steffan-Dewenter & Tscharntke, 1999). Bolger *et al.* (1998) also demonstrated that other orders, such as Diptera and Coleoptera, had a greater presence in interior, compared with perimeter, areas. However, a report on fragmented areas within the National Botanic Gardens in Pietermaritzburg (South Africa), showed that Blattodea, Hemiptera and Diptera avoided edges, while Hymenoptera, Arachnida and Orthoptera showed no preference for either edge or core areas, and were well represented in both habitat types (Ingham & Samways, 1996). All these studies concluded that variation in abundance could be caused by altered microclimatic and habitat quality within edge areas.

It would be expected that remnants, similar to those used in this study, that abut cleared fields, would have variation in abiotic factors. Evidence has been presented to show that at the interface of such areas, microclimate will oscillate between the two different systems, and there may be a temperature gradient across the remnant, as well as fluctuation in light intensity and variation in air and soil moisture levels (Chen *et al.*, 1990; Matlack, 1993; Young & Mitchell, 1994). These altered
conditions have the potential to cause a domino effect on changes in edge inhabitants (Saunders et al., 1991; Murcia, 1995; McLeod & Gates, 1998). For example, arthropod diversity may decline in areas where altered microclimatic conditions have changed the vegetation structure at the edge (Bromham et al., 1999; Davies et al., 2001; Foggo et al., 2001).

Two of the major abiotic factors known to affect arthropod survival, microclimate and light penetration (Ingham & Samways, 1996), were found to be similar between the two habitat types investigated in this study (Baiada, 2002). This could account for why diversity was similar between the core and edge, but perhaps not explain why abundance was higher in the edge compared to core areas, particularly in terms of Hymenoptera and Blattodea.

Arthropod abundance may have increased in the edge of these Cumberland Plain remnants because they were acting as a corridor for migration between the core and the adjacent ecosystem. The use of edges as corridors for movement has rarely been reported, although often species assemblages in perimeters consist of invertebrates common to both the original habitat and those found within the newer, adjacent ecosystem. As a result of this observation, it has been speculated that arthropods utilise edges as the entrance and exit point between the interior and outside ecosystems (Usher et al., 1993; Tscharntke et al., 2005a). The butterfly, Parnassius smintheus, (distributed throughout the Rocky Mountains in Canada) was observed to move through edge, although they did not remain to occupy the area (Roland et al., 2000; Matter et al., 2004; Ross et al., 2005). Kiffney et al. (2003) determined that insect abundance increased in edge areas of riparian zones of streams of south-
western British Columbia (Canada), as the insects moved from riparian to aquatic ecosystems. If the arthropods encountered in this study are utilising the edge areas as a corridor between remnants, it could explain why the abundance ranking altered only slightly between core and edge areas of remnants.

Alternately, the generational turnover of arthropods is much faster than those of its other co-inhabitants of these remnants (i.e. birds and skinks), and as such they may be able to undergo morphological changes more rapidly that better enables them to respond to edge areas (Ewers & Didham, 2006). For example, butterflies have increased their muscle mass in fragmented landscapes, making it possible for them to transverse the edge and migrate to new areas (Norberg & Leimer, 2002). Being able to cope in ones own environment is essential to survival. Likewise, taxonomic survival relies on migration of new individuals into populations to ensure the gene pool does not decline. Arthropod movement between an edge and the surrounding matrix is an influential factor in arthropods being able to survive in remnants (Rand et al., 2006). The process of recruitment both from within and outside the remnant may also have influenced the observed similarity between the core and edge of the remnants studied.

The overall similarity in diversity, with relatively limited differences in abundance indicated that, at least in the Cumberland Plain woodland remnants studied, arthropods were not adversely affected by edges, or because of the remnants size, the entire remnant area may act as an edge to these invertebrates.
3.4.2. Skink Abundance and Diversity.

The four species of small sinks (L. guichenoti, L. delicata, C. virgatus and S. mustelina) previously known to occupy the local remnants (Anderson & Burgin, 2002; White & Burgin 2004), were also encountered in this study. Their abundance differed among species and between the core and edge of remnants.

*Lampropholis guichenoti* were encountered more frequently than any other species, although *L. delicata* was also relatively common. The less commonly encountered species, *C. virgatus* and *S. mustelina*, were not observed in sufficient numbers to make any determination of the impacts of edge on their distribution. The woodland remnants studied did not include their preferred habitat (Swan, 1990; Griffiths, 1997).

The distribution patterns of the *L. guichenoti* and *L. delicata* across the perimeter and interior of the remnants was consistent with previous findings (Anderson & Burgin 2002). However, Bragg *et al.* (2005) conducted studies within a mine regeneration site at Tomago (NSW, Australia) and determined that *L. delicata* were interior specialists. This finding was not supported by the outcomes of the present study.

The premise of interior and edge specialists is well documented with regard to vegetation (e.g. Ranney *et al.*, 1981; Panetta & Hopkins, 1991; Burke & Nol, 1998), and specialist animal species (e.g. Sarre *et al.*, 1995; Laurance & Laurance, 1999; Sumner *et al.*, 1999). The distribution of some species, because of the more stringent requirements for survival, may be restricted, due mainly to abiotic conditions. This
creates a different assemblage of species within each habitat. As a consequence, the concept of ‘edge’ and ‘interior’ specialists was coined. Interior specialists are excluded from edges and, therefore, migration is often hampered (Yahner, 1988). *Lampropholis delicata* has been considered a generalist species, and no other study has indicated that they are likely to display interior speciality. The population of *L. delicata* studied by Bragg, *et al.* (2005) may therefore be unique to Tomago Sandbeds due to specific climatic conditions, or because they are at the extreme edges of the species range (see Cogger, 2000).

More broadly, the contrast in dispersal patterns of these two *Lampropholis* sp. is indicative of edge avoidance. While species may be found in perimeter areas, they are usually present in lower numbers. For example, some populations of frogs and salamanders have been reported to avoid edges because the loss of native vegetation and the introduction of agriculture have left ‘hard’ edges that are devoid of appropriate habitat (Demaynadier & Hunter, 1998; Voss & Chardon, 1998).

Previous researchers (eg. Sisk & Margules, 1993; Hadden & Westbrooke, 1996) have observed enhanced herpetofaunal richness with increased distance from the edge of a remnant. This pattern of distribution has also been observed in other species. For example, in Finland the fungus *Fomitopsis pinicola*, had a reduced presence in edge areas compared to interior regions of remnant forests (Siitonen *et al.*, 2005) while in Switzerland fens *Primula fainosa* showed the same distribution (Lienert & Fischer, 2003). Similar behaviour has been observed in the bush rat, *Rattus fuscipes*, within rainforest remnants of Queensland, Australia (Laurance,
1991) and the blue crab, *Callinectes sapidus*, in seagrass fragments of Virginia, USA (Hovel & Lipcius, 2002).

One reason often cited for low representation of a species in edges is that of unfavourable habitat variation (Murcia, 1995). This variation occurs when habitat is removed, and replaced with an alternative ecosystem. Only those species that have a pre-adaptation to the ‘new’ habitat will remain ‘out on the edge’ (Yahner, 1988). For example, due to the more open vegetation located at the perimeter, the invading Argentine ant *Linepithema humile*, became established in Californian riparian corridors and successfully out competed native ants. Approximately 50m from the edge, the habitat more closely approximated the local endemic dry scrub, and here the exotic species was excluded, and the native ants were present in relatively larger numbers compared to the edge. Holway (2005) suggested the differences were due to the adaptation of native ants to the dry scrub and, although they were not absent from the perimeter area, they were not present in sufficient numbers to offer substantial resistance to the invading exotic ants.

As previously indicated, the skinks of this study are generally considered habitat generalists since they are able to re-establish within disturbed habitats (eg. Lunney *et al.*, 1991; Twigg & Fox, 1991) and they are able to cope with human modified areas, including urban gardens (Burgin, 1993), provided that there are sufficient foraging, basking, shelter and breeding sites for the skinks to survive successfully in the area (Mather, 1989).
As previously indicated, Anderson and Burgin (2002) examined the study sites used in the current study and concluded that both edge and core areas provided equivalent habitat elements (e.g. contained sufficient numbers of logs for basking and sheltering and ground cover for protection), and suggested that the differences in skink numbers were not related to available habitat elements.

Skinks could utilise edges in the process of dispersal. This could explain why Anderson and Burgin (2002) encountered more sub-adults in edge areas than adults or juveniles. Dispersal of sub-adult offspring into new territory is known for other lizards (e.g. bronze anole, *A. aeneus*; Stamps & Eason, 1989), and some mammals (eg. Red squirrel, *T. hudsonicus*; Anderson & Boutin, 2002). Sub-adult *Lampropholis* sp. may disperse from the core to the edge to establish new territories away from competing adults. Such dispersal into new areas facilitates the spread of the gene pool through the potential increase in encounter with unrelated mates (Banks *et al*., 2005). However, they were shown to be in smaller numbers within the edge environment at maturity, despite the presence of breeding and foraging sites.

There is evidence to suggest that juvenile and sub-adults fare differently in edge areas. Juvenile yellow-footed antechinus, *Antechinus flavipes*, were better equipped to deal with edge effects than were more mature cohorts (Marchesan & Carthew, 2004). The young of red squirrels, *T. hudsonicus*, born in edge habitats, had enhanced survival compared to older squirrels that migrated into the area, mainly because the migrants were less able to cope with the harsher conditions (Anderson & Boutin, 2002). Similarly the perennial herb *Trillium camschatcense* was able to establish in edge areas but, due to microclimatic conditions, died off before maturity.
and reproduction occurred (Tomimatsu & Ohara, 2004). Based on these results, and their propensity to disperse, sub-adult skinks would be the first to experience a decline in edge areas, unless extreme conditions occur that may force other age groups to also disperse into edge areas (see Section 4.4.1). However, given that the skinks encountered in this study are generalist species, it is unlikely that one cohort would be more susceptible to the harsher environment in edges than any other.

### 3.4.3. Avian Abundance and Diversity.

The avian assemblage showed a difference between the core and edge areas of the study remnants. The birds observed at these sites appeared to respond to these remnants in different ways; edge (e.g. Ardea ibis – cattle egret), or interior (e.g. N. temporalis - red-browed finch) specialist and edge (e.g. Coracina novaehollandiae) or interior (e.g. M. melanocephala - noisy miner) avoiders.

This behaviour is consistent with observations made in previous studies. Scott et al. (2006) indicated that of the 70 species of birds encountered in arid spiny forests of Madagascar, only 26% inhabited edge areas. They also showed that the divide between interior and perimeter specialists was consistent with dietary requirements. Terrestrial and aerial feeders preferred edge areas, whilst arboreal foragers were more likely to be interior specialists. Berry (2001) determined that fragmented forests in southern Victoria (Australia) suited forest-edge specialists, such as the grey fantail (Rhipidura fuliginosa), rather than open country avian species. This was due to differential foraging opportunities. Catterall, et al. (1991) determined that small insectivorous birds avoided edges in forest-shrub interfaces of Brisbane (Australia).
Habitat preference of the bird species encountered in this study appeared to be delineated on foraging behaviour. For example, the seven species with greatest abundance on the perimeter were predominately terrestrial foragers (e.g. Australian raven *Corvus coronoides*) or aerial/terrestrial hunters (e.g. Australian magpie *Gymnorhina tibicen*; cf. Barker & Vestjens, 1984a). In contrast, the avian that utilised the core (e.g. red-browed finch *N. temporalis*) were more likely to be arboreal foragers (cf. Barker & Vestjens, 1984b). However some species, for example, the galah *C. roseicapilla*, which can also forage aborally (cf. Higgins, 1999), were encountered exclusively in the edge of remnants. Foraging behaviour (in terms of terrestrial, aerial or arboreal) may, therefore, be a causative effect in some bird species, although it was not the only factor that delineated avian habitat preferences.

A combination of remnant size, loss of habitat diversity, and foraging mode contributes to edge/core use by birds (Thiollay, 2002). For example, in coastal temperate forests of Vancouver Island (Canada), avian species richness declined between the core and edge of small remnants. Interior specialists were absent from these areas for at least three years after edge creation (Shirley & Smith, 2005). Major *et al.*, 2001) determined that small insectivorous birds (usually arboreal feeders) needed remnants of not less than 200 ha in order to maintain a substantial numbers of these birds throughout the remnant. They further demonstrated that in areas <100 ha, larger sized birds and terrestrial/aerial foragers dominated. A major reason for this effect was considered to be the loss of suitable habitat. This was also assumed to be the reason for the decline in bird diversity in fragmented forests of
Kayu Mas Boreno (Cleary et al., 2005) and loss of species from edges within small (< 49 ha) forest fragments, created ≤ 50 years ago, on Singapore Island (Castelletta et al., 2005).

The bird distribution observed in the current study was different to the findings of previous researchers. As previously stated the remnants were at least 100 years old and small (between 20 and 176 ha). Those present, however, tend to be interior specialists (e.g. tree martin, Hirundo nigricans) and not strictly insectivorous. For example, in addition to insects, both the red-browed finch (N. temporalis) and willie wagtail (Rhipidura leucophrys) consume grains (Barker & Vestjens, 1984b). In addition, some interior specialists are medium-sized (i.e. between 20 and 40 cm), generalist feeders (e.g. noisy friarbird Philemon corniculatus; cf. Marchant & Higgins, 1990). It is, therefore, likely that other ecological factors contributed to bird distribution in these remnants.

The avian utilising edge areas were typically larger birds that are antagonistic in nature. For example, Australian magpie (G. tibicen), white-winged choughs (Corcorax melanorhamphos) and noisy miner (M. melanocephala; Cox & Bauer, 1997; Grey et al., 1998), are strongly territorial and rely on noisy and aggressive behaviour to fend off both competitors and predators.

Another successful tactic utilised by some larger birds is flocking. Birds, such as the white ibis (Threskiornis molucca), cattle egret (A. ibis), and various parrot species tend to move into areas in numbers, pushing out all but the most aggressive inhabitants (Miller & Cale, 2000; Collis, 2002; King, 2002).
These behaviours have been linked to the exclusion of small and, at times, medium-sized birds from areas. In remnant eucalypt woodlands (Lurg, Victoria, Australia), Grey et al., 1997) demonstrated that a reduction in noisy miner numbers in edges of even small remnants (<8ha) resulted in an increase in the number of smaller birds, regardless of foraging technique. The change in abundance was confirmed in grey box woodlands remnants (Violet Town, Victoria, Australia; Grey et al., 1998). A similar study undertaken in eucalypt open-forest and woodland remnants in Brisbane (Australia) showed that the hyper-aggressive behaviour of noisy miners was the major reason for the exclusion of smaller and less aggressive bird species (Piper & Catterall, 2003). This exclusion of these more ‘timid’ birds was assumed to reduce interspecific competition for food (Grey et al., 1997, 1998).

At least for some of these aggressive birds, there is a predilection for occupying edge areas of remnants. For example, Cox and Bauer (1997) demonstrated a correlation between an increase in white-winged chough numbers and edges in Bathurst (Australia). They concluded that these animals are predominately forest species that also like to forage in grasslands. Occupation of edge areas enables them to utilise both types of habitat.

The increase in the presence of these types of birds in edges has also been linked to their ability to modify their behaviour to include anthropogenic structures and facilities. Keast (1995) suggested that larger birds, such as those encountered in this study, have increased in abundance and diversity, in areas dominated by humans because they are able to supplement their natural diet with food provided by people. My observations during this study were that such species use powerlines, fences and
even house roof tops to observe and launch attacks on prey in perimeter areas. For example, the laughing kookaburra (*D. novaeguineae*) encountered in edge areas entered the edges of remnants for prey after observing them from powerlines in the cleared areas adjacent to the remnant. Predation may be reduced in the interior areas due to a lack of such structures. This behaviour has also been reported among birds in urban areas surrounding oak woodlands (California; Blair, 1996). Small mammals used power poles and the area surrounding them, to hide and watch for movement of prey in the edge areas of forest in East Tennessee (U.S.A.; Johnson *et al*., 1979).

Birds most likely to utilise edges are, therefore, those that can forage successfully in both edge and adjacent areas, and defend those areas (McCollin, 1998).

### 3.4.4. Remnant Community Structure.

The three trophic levels examined within the Cumberland Plain woodland remnants differed in diversity and abundance between the perimeter and interior habitat types.

While arthropods appeared to be the least affected, the diversity and abundance of birds and skinks contributed most to the overall differences between the edge and core. In general, however, skink numbers were lower in edges, while avian avoid edges or interiors dependent upon species.

Such results are consistent with studies conducted in arid spiny forests of Madagascar where Scott *et al*. (2006) showed that lizard abundance was adversely affected by clearance, even 60 years after the event. Bird populations remained
mixed and some preferred interior habitats while others remained in edge areas. Other species appeared to avoid one of these areas and inhabited the alternative habitat.

As a result of clearing a shift may occur in community dynamics as some species are excluded from areas or at least the numbers they can maintain are restricted in that habitat.

In the following chapters the interactions among the skinks and their major predators (birds) and prey (arthropods) are investigated in more detail. Of particular interest is the observation that while overall arthropod abundance and diversity is similar across core and edges, the prey taxa (and perhaps size) targeted by small skinks, may vary across habitats. Likewise avian presence/absence from a habitat may affect numbers in terms of competition with skinks or through skink predation by birds.
Chapter 4 – Skink Abundance and Diversity

4.1. Introduction

The world’s landscape is changing, from native forests to anthropogenic dominated areas (Fox, 1990; Saunders et al., 1991; Hawlena et al., 2004). In Australia, endemic remnants continue to shrink rapidly (Ferreira et al., 2001; Hazell, 2003; Possingham, 2003; Catterall, 2004). The consequences of this are that there are greater numbers of isolated, irregularly shaped fragments of native vegetation than in the past (Murcia, 1995; Bennett, 2000).

The ecological functioning of these remnants alters as they are influenced by adjacent land use (Davies et al., 2001). Exchanges of energy, nutrients and competitive species occur across mutual boundaries, often referred to as edges (Matlack, 1993; Young & Mitchell, 1994; Babbit & Tanner, 1998; Bromham et al., 1999; Morita & Yamamoto, 2001).

These edges have been a concern to ecologists over time. As a consequence, the impacts on ecological and population processes have been widely discussed and reviewed (e.g. Yahner, 1988; Murcia, 1995; Kremsater & Bunnell, 1999). However, there appears to be as much variation in the results of these studies as there are different types of biodiversity scattered throughout the world. This is perhaps due to a research emphasis on tropical remnants (Laurance, 1991) and regenerated areas (Fisher, 2001). Results of these may not be replicated in other habitat types, such as...
woodlands, or even in similar habitats located in other land masses. Equally, research has concentrated on the possible edge effects experienced by avian (e.g. Angelstam, 1986; Berry, 2001; Brand & George, 2001; Arnold, 2003), arthropods (e.g. Courtney & Courtney, 1982; Didham et al., 1996; Cappuccino & Martin, 1997; Bolger et al., 1998), and mammals (Gates, 1991; Downes et al., 1997; Goldingay & Whelan, 1997). While there have been studies conducted outside of these parameters, there has been a lack of information generated on edge effects on reptiles, particularly in Australia.

Despite a substantial diversity of skinks inhabiting a wide variety of habitats throughout Australia (Greer, 1989), reptile usage of edge areas of remnants has received limited attention and most information has been gained from studies conducted elsewhere (e.g. Gregory, 1978; Meik et al., 2002; Lehtinen et al., 2003; Gray et al., 2004).

One of the few studies that have been undertaken on such species was reported by Anderson and Burgin (2002). They investigated the effects that edges have on small generalist skinks in peri-urban Sydney, Australia. They observed that abundance of *L. delicata* and *L. guichenoti* was significantly lower in edge areas, compared to the interior of the remnants. These findings were in contrast to conventional wisdom that would predict that these lizards would be readily found in edges because of more suitable climatic conditions (Kremsater & Bunnell, 1999), and the observation that they are abundant in urban gardens (Burgin, 1993).
Baiada (2002) undertook an investigation of the habitat characteristics (e.g. ambient temperatures, light penetration) in Anderson and Burgin’s (2002) remnants that commonly influenced the distribution of small ground dwelling fauna. He observed no structural, or microclimatic conditions that could account for the differences in skink numbers between the fringe and core of these small, long established remnants (some >100 years post-fragmentation).

Given these findings, it may be asked was Anderson and Burgin’s (2002) study an anomaly or do skinks continually encounter negative edge effects in the perimeters of these woodlands that result in reduced occupation of these areas?

The following questions are investigated in this chapter:

- Does the composition of small skink assemblage vary over time?

- Is the pattern similar between seasons or do small skinks utilise edge and core areas differently at different times of the year?


Selection of sites is presented in Chapter 2.

Skink data were collected as described in Chapter 3.2.1.
To determine temporal patterns of skink distribution between the edge and core of remnants, data collected in this study were compared to that collected in the same sites in 1999 by Anderson and Burgin (2002). To provide for a valid statistical comparison of data taken at different times and at different sampling intensity, for the raw data were divided by the number of human-hours used in its collection and multiplied by 100.

Other procedures used in the analysis of data are presented in Chapter 3.2.4.

**4.3. Results.**

**4.3.1. Distribution patterns between years.**

In 1999 a total of 216 individuals from three species (*L. guichenoti, L. delicata* and *C. virgatus*); 164 on core sites and 52 on edges sites were encountered. In 2001, overall there were 486 individuals encountered. After adjustment the 2001 study equated to 297 individuals; 220 on core sites and 77 on edge sites (Figure 4.1 and 4.2). In both years the edge and the core were different in abundance and diversity. The separation between edge and core was greater in 2001 (*R = 0.646, P = 0.029*) than in 1999 (*R = 0.417, P = 0.029*). In both years there was greater similarity within the site types than between the edge and core sites. In 1999 core sites were more similar (97.8%) than edge sites (69.4%; Figure 4.3). Likewise in 2001, core sites were more similar (92.2%) than edge sites (73.2%; Figure 4.4).
Figure 4.1. Mean number (S.E.) of small skinks encountered at the edge (■) and core (■) of woodland remnants in peri-urban north-western Sydney, in autumn/spring 1999 and autumn, spring 2001, and summer 2002.

Figure 4.2. Mean number (S.E.) of *L. guichenoti* (■), *L. delicata* (■) and *C. virgatus* (■) encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney during autumn/spring 1999, autumn, spring 2001, and summer 2002.
Figure 4.3. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) in 1999. Core sites displayed greatest similarity as a group (average 97.8%). Edge sites were less similar than core sites (average 69.4%). There were differences in abundance and diversity between edge and core sites ($R = 0.417$, $P = 0.029$).

Figure 4.4. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) in 2001/02. Core sites displayed greatest similarity as a group (average 92.2%). Edge sites were less similar than core sites (average 73.2%). There were differences in abundance and diversity ($R = 0.646$, $P = 0.029$).
4.3.2. Distribution patterns between seasons.

Seasonal variation occurred within and between the years. In autumn 1999 the edge and core were similar ($R = 0.141, P > 0.143$). However, Core sites were more similar (group average 90%) than edge sites (60.8%; Figure 4.5). The similarity between edge and core areas lessened in autumn 2001, but was still significant ($R = 0.281, P = 0.057$). The core sites were more similar (76.8%) than edge sites (67.5%; Figure 4.6).

The spring months in both 1999 and 2001 demonstrated a greater degree of separation between edge and core areas than the other two seasons (autumn and summer). In spring 1999 there was no similarity between the edge and the core ($R = 0.656, P = 0.029$), and the core sites were more similar (91.1%) than edge sites (65.3%; Figure 4.7). In spring 2001 there was also no similarity between the edge and the core ($R = 0.584, P = 0.029$). The core sites were more similar (93.2%) than edge sites (70.6%; Figure 4.8).

In the summer of 2002 the edge and core sites were similar ($R = 0.115, P = 0.2$). The core sites were more similar (90%) than edge sites (70.7%; Figure 4.9).
Figure 4.5. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for autumn 1999. Core sites displayed greatest similarity as a group (average 90%). Edge sites were less similar than core sites (average 60.8%). Edges sites had greater similarity to core sites than to each other ($R = 0.141, P = 0.143$).

Figure 4.6. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for autumn 2001. Core sites displayed greatest similarity as a group (average 76.8%). Edge sites were less similar than core sites (average 67.5%). Both edge and core sites were similar ($R = 0.281, P = 0.057$).
Figure 4.7. MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for spring 1999. Core sites displayed greatest similarity as a group (average 91.1%). Edge sites were less similar than core sites (average 65.3%). There is no similarity between edge and core sites ($R = 0.656, P = 0.029$).

Figure 4.8 MDS plots (derived from Bray-Curtis similarity) based on skink abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲) for spring 2001. Core sites displayed greatest similarity as a group (average 93.2%). Edge sites were less similar than core sites (average 70.6%). There is no similarity between edge and core sites ($R = 0.583, P = 0.029$).
4.4. Discussion

4.4.1. Distribution patterns between years.

Skinks were encountered at more than double the number in the interior of the remnants than on the perimeter. This pattern was consistent over time, although the amplitude of the difference varied. This could be due to fluctuations in climatic conditions between years. In 1999 there was a drought throughout New South Wales. The effect of low rainfall during this time could have impacted on skink distribution by forcing them to seek more amenable environs. During 2001 the drought (at least in the Hawkesbury local area) eased with rainfall increasing from 2002 onward, thereby potentially changing microhabitat conditions for skinks (Figure 2.3).
Rainfall, or lack of it, has been linked to changes in abundance of species within edge and core areas of remnants. For example, in Brazil, Sofia et al. (2004), demonstrated that rainfall was related to occupation of edge and core by euglossine bees. Other researchers that have addressed rainfall effects, or more specifically drought, have commented on the effects on abundance and diversity over the whole remnant (e.g. Lunney, 1987; Pinheiro et al., 2002). One such study demonstrated that both *L. guichenoti* and *L. delicata* numbers were adversely affected by drought in the Mumbulla State Forest, (south coast of NSW; Lunney, et al. 1991). The drought event that encompassed the study area throughout 1999 may have dried out the core to a level where its microclimate was broadly equivalent to the edge. This could have resulted in skinks occupying the interior area radiating out towards the edge, in the search for more optimal conditions (such as water and prey). This could explain why skink abundance in core and edge, while still displaying some differences, were more similar during this period, with regard to abundance and diversity than 2001.

Lunney, et al. (1991) observed that *L. guichenoti* and *L. delicata* had difficulty re-establishing pre-drought numbers after a drought event. Their encounter rates with these *Lampropholis* species were lower than in pre-drought surveys and for up to two years after the drought broke. In the present study numbers of small skinks were greater in 2001 than in 1999. The core area of the remnants may have recovered sufficiently to sustain increased numbers of skinks. Both *Lampropholis* species investigated may ‘double clutch’ under appropriate conditions. For example, a study of a population of *L. guichenoti* in the Sydney area, revealed that females produced a
second set of follicular growth, followed by ovulation, in the early summer months (Joss, 1985; Joss & Minard, 1985).

Coincidently, males underwent a second wave of spermatogenesis at this time (Joss 1985). It was concluded that, under appropriate climatic conditions, this could result in a second clutch of eggs being laid. Joss and Minard (1985) also observed similar reproductive behaviour in L. delicata. Rainfall was higher in 2000 and resident skinks had increased in number by 2002. However, this scenario does not explain the variation in abundance between core and edge, unless other abiotic factors continued to impact on the perimeter area.

Harsh environmental conditions can create high levels of stress in both fauna and flora and this may contribute to increased disease and/or mortality rates. For example, in a two year study near Stillwater Lake (Nevada, USA) it was observed that 16,000 birds died from drought induced disease (Oleson & Carr, 1990). Yellowstone cutthroat trout Oncorhynchus clarki bouvieri endemic to Montana (USA), had an increase in whirl disease during drought, which was linked to increased mortality and decreased reproductive rates (Koel et al., 2005). Although, there were no indications of disease in skinks encountered in this study, drought could have affected body condition and thus the health of individuals. This could result in the distribution of animals within the remnants altering between the years, but does not explain why there were fewer skinks in edge areas.

Leaf-litter decomposition rates may occur at up to 3 - 4 times faster at the edge than in the interior of tropical rainforest remnants (Didham, 1998). It has been suggested
that edges experience drier microclimates than the internal segments of remnants. This could impact upon the decomposition rate of litter, and may change the makeup of the litter on the ground (Didham & Lawton, 1999). Such changes could impact on small skinks that require ground cover in order to forage successfully, and to escape from potential predators (Mather, 1989). If the litter at the edge of remnants consisted of a thin dry layer, skinks and their prey may view these areas as unsuitable, as their movement through such an environment may draw the attention of potential predators. Anderson and Burgin (2002) found no significant variation in leaf litter depth between core and edge of these remnants, although soil moisture and light levels differed between the two habitat types (Baiada 2002). However, these data indicated that edges were moister, not drier. It is unlikely, therefore, that leaf litter decomposition rate contributed to a variation in skink numbers in these areas.

Another potential cause of edge and core population variation is the age of the remnant. Recently created edges may serve to temporarily increase species diversity and richness, although over time abundance and diversity will decline to a new equilibrium (Essen, 1994; Hadden & Westbrooke, 1996). For example, Hagan, et al. (1996) conducted studies on bird numbers in fragments in Maine (USA), and determined that abundance increased within a short time of initial edge creation, but inevitably subsequently declined. Amphibian and reptile diversity have been shown to decrease in newly created edges, but later increase, and then decline again as regrowth became more prevalent (Lunney et al., 1991; Demaynadier & Hunter, 1998). Likewise, Californian red-backed voles C. californicus were scarce after
initial disturbance due to habitat removal, and recovered after six years of regrowth (Tallmon & Mills, 2004).

The edges utilised in this study were created decades before the study was undertaken and there has been no appreciable ongoing human disturbance. Based on previous studies on the sites (Anderson & Burgin 2002; Baiada 2002) it was concluded that edge areas of the remnants had stabilised post-fragmentation and the edge creation would not be the direct cause of skink distribution.

4.4.2. Distribution between seasons.

Small skinks displayed seasonal variation in their use of core and edge sites, and this variation was consistent between the years 1999 and 2001/2.

During summer 2002, skink abundance and diversity were similar between core and edge areas. This may be indicative of the more severe climatic conditions experienced in that year, compared to 1999, rather than a true indication of seasonal variation. During December 2001 bushfires ringed the area. These fires were immediately followed by heavy rainfall which caused localised flooding throughout many of the study sites. These events could have resulted in the skinks dispersing throughout the remnants seeking alternative habitat, thereby causing edge and core similarity. In small remnants, the harsher aspects of the Australian climate may have a greater impact than edge/core effects (Lunney et al., 1991).
Overall, abundance of skinks found in edges and cores were more similar in autumn than in spring and summer. In contrast, the differences between the two habitat types were greatest in spring. These findings are consistent with previous studies (e.g. birds in edge/core areas of Andean forests; Herzog et al., 2003). It was observed that bird use of habitats varied among seasons. There are usually two explanations provided for such seasonal variation (Griffiths & Simpson, 1966; James & Shine, 1985; Pinheiro et al., 2002). The first is consistent with reproductive behaviour while the second is associated with movement generated by prey migration. Migration between edge and core could also occur in response to predator avoidance.

In terms of reproductive behaviour animals may exclusively use an area of their home range for mating and breeding (Smith, 1985). For example, white-lipped peccaries (Keuroghlian et al., 2004) and black lemurs (Bayart & Simmen, 2005) will travel vast distances within their home range to meet in breeding season in one specific area in order to mate and/or reproduce.

It has been observed that in remnants, such behaviour may be mimicked by some species that utilise edge and core areas differently in breeding season. For example, black rat snakes *E. obsoleta obsolaeta* copulate in the core of forest remnants in Ontario (Canada). However once gravid the females move to the edge of the forest, and remain there until they lay their eggs. They subsequently return to the core (Blouin-Demers & Weatherhead, 2001).

In this study the breeding cycle of the *Lampropholis* skinks, may mimic the patterns observed in seasonal shifts of other species. Both *L. guichenoti* and *L. delicata* mate
during the warmer months of October through to February (Joss & Minard, 1985; Simbotwe, 1985b). This would suggest that movement either to the edge or the core to locate a mate would occur during the spring months. The greatest separation of abundance and diversity between the two habitat types (i.e. edge and core) occurred during spring. Breeding skinks may move into the core to copulate and the females to remain to nest. The emerging neonates would then remain in the core until reaching sub-adulthood when they may disperse (as discussed in Section 4.4.1). Immature and non-breeding animals may be reluctant to move away from the edge during the breeding season, and thereby skinks remain in edge areas (Fraser & Stutchbury, 2004). This may well explain the pattern of cohort distribution reported by Anderson and Burgin (2002) where a greater portion of adults and juveniles were present in the interior, while sub-adults appeared more abundant in the perimeter, including during the spring months.

There is another factor concerning breeding behaviour that may influence skink movement. Communal nesting sites are utilised by both Lampropholis species studied here (Wells, 1981). Gravid females congregate to take advantage of preferred nesting sites. As the neonates emerge from the nest they would at least initially, be in greatest numbers in the general vicinity of the nest. The observations of Anderson and Burgin (2002) would indicate that since sub-adults were most abundant in edge areas, preferred nesting sites would be in greatest abundance at the core of remnants. However, while they found no evidence to suggest that potential nesting sites (e.g. fallen logs, large rocks) were in greater density in the perimeter of the remnants, it may well be a case of skinks returning to well established nesting sites in the core, rather than looking for new ones in edge areas.
The seasonal pattern of movement could be indicative of anti-predator behaviour, as opposed to foraging behaviour. One of the major predators of small skinks is avian (Greene, 1988). Bird utilisation of fragments has been linked with changing seasons (e.g. Seddon & van Heezik, 1996; Aumann, 2001). Some birds utilise alternative segments of fragments at different times of the year, but there is often a seasonal turnover of diversity. For example, Arnold (2003) observed that there was a peak in the number of arthropod taxa utilising woodland remnants (in Western Australia) during autumn (15 species) compared to other seasons. The least diversity (six species) was recorded in winter. The alternation of species richness according to season has also been observed in other remnants (e.g. Reid et al., 2002; Fraser & Stutchbury, 2004). Seasonal changes in bird numbers and/or diversity in the edge and core of remnant Cumberland Plain bushland could equate to the opposite seasonal movement of small skinks between these habitat types, as they attempt to avoid their predators. Alternatively, the impact of their predation could result in a reduction in numbers that are replenished from the core, such that the edges act as a sink.

Seasonal occupation of habitat has also been linked to food availability. For example, both the bridled nailtail *Onychogalea fraenata*, and black-striped wallabies *Macropus dorsalis* select different habitat and diet in the wet season compared to the dry season (Evans & Jarman, 1999). The blacked-eared opossum *Dipodelphis aurita* also displayed seasonal variation in foraging range in the forest fragments of Brazil, as it moves in response to food availability (Cáceres & Monterio-Filho, 2001). The seasonal pattern of skink distribution observed in this study could mimic the migration path of suitable prey, since arthropods have demonstrated seasonal use of
habitat, as they themselves search for food. Abbot et al. (1999) reported that a turnover of arthropod guilds occurred in *Eucalyptus globulus* plantations with season. For example, sapsucker biomass increased during the flowering season (late autumn, early spring), and chewing insects dominated in the other parts of the year.

The small skinks of this study are considered diet generalists and are restricted to taking prey that they can easily handle and consume (Wourms & Wasserman, 1985; Warner, 1995). During autumn suitable prey may be reduced in number in either the core or the edge, prompting movement of skinks between the areas.

The following chapter examines the effect prey availability has on skink distribution throughout the remnants studied.
5.1. Introduction.

Ecologists have long tried to determine the effects disturbance and habitat decline have on the interaction among various co-existing species of an ecosystem (Serio-Silva & Rico-Gray, 2002). More specifically, the effects a reduction in habitat has on the interactions of predator and prey (Cardinale et al., 2006).

The predator/prey relationship plays an integral role in community structure, with the number of predators and the rate they consume prey determining many of the overall ecosystem dynamics (Miller et al., 2006). Diet is crucial to animal well-being and the availability of suitable prey may affect the distribution of predators throughout the landscape (Cooper & Vitt, 2002).

In modified habitats, such as edges, there have been reports on changes to competition, predator/prey and parasitic interactions, as well as overall resource availability (Gates, 1991; Saunders et al., 1991; Kilgo, 2005). Murcia (1995) used the following example to highlight this effect. Altered light intensity may cause a leaf flush on some plants, which attract herbivorous insects into the area. This increase in insect numbers (prey) may entice nesting birds into the edge. These, in turn, can attract nest predators and brood parasites. As a result the dynamics of the local environment may be changed.
Edges have long been viewed as problematic in the interaction between predators and prey. This type of habitat alteration has been inevitably described as barriers (Bider, 1968) or funnels for predator movements (Dyer et al., 2001). In terms of the effects on prey, persistent edges may make them more vulnerable to attack (Ferguson, 2004b). Alternatively, altered vegetation structure can result in reduced prey presence due to habitat loss (Lima & Dill, 1990). Despite these impacts, most data have been collected on the role edges play in creating a flux in predator numbers (e.g. Angelstam, 1986; da Fonseca & Robinson, 1990; Ferguson, 2000; Cantrell et al., 2001; Fernandez-Juricic et al., 2001; Lahti, 2001; Bommarco & Fagan, 2002; McLain et al., 2005). However few studies have investigated the role of edges on the abundance of natural prey and the subsequent effects this could have on their traditional predators (exceptions include Ferguson, 2004b; Baxter et al., 2005). If prey species cannot maintain viable populations within edge habitats, their natural predators would be impacted. Such changes in arthropod populations in core and edge areas of small remnants would be expected to have an impact on the dynamics of resident native predators, such as the small skinks Lampropholis guichenoti and L. delicata.

Fluctuating microclimatic conditions, including light levels associated with edge habitats, have been reported to encourage arthropods into these areas (Kremsater & Bunnell, 1999). As a consequence, they are greatly advantaged by conditions on fragment edges (Cappuccino & Root, 1992; Roland & Kaupp, 1995). For example, carabid and spider populations increased in edges of woodland remnants (in York England) as a consequence of higher air temperature compared to core areas (Bedford & Usher, 1994).
Altered vegetation structure within perimeter areas, compared to core areas, has also been observed to benefit arthropod populations. Plants with dense foliage often dominate edge areas and these may benefit herbivorous organisms, including insects (Murcia, 1995). For example, some Lepidoptera have shown a preference for edge habitat for oviposition (Courtney & Courtney, 1982), possibly due to increased leafy plant abundance (Cappuccino & Martin, 1997), or warmer temperatures. As a consequence larvae and nymphs of such taxa may be in greater abundance within edge zones, compared to interior environments (Wolda, 1978; Cappuccino & Martin, 1997).

When arthropods are attracted to edges, it is assumed that their predators, such as skinks, are likewise attracted to perimeter areas. Although birds have been considered the foremost insect predator, lizards are also a primary predator of arthropods (Hooks et al., 2003). For example, both L. guichenoti and L. delicata have been reported to be generalist arthropod predators. They take both aerial-arboreal and ground-dwelling invertebrates (Rose, 1974; Lunney et al., 1989). Although there is variation in the diet of these congeneric, there is overlap in prey selection (Lunney et al., 1989; Warner, 1995). Based on these observations, and the apparent predilection of arthropods to inhabit edges, it was likely that the skinks of this study would follow this trend. However, in the previous chapters it was suggested that they may avoid edges, and therefore, not follow prey into the area. Although arthropods may be well represented in edge and core habitats, the proportion that would be attractive to skinks as prey may be in lower numbers (or absent) within perimeters. This is because skinks encountered in this study may
prefer prey (arthropods) of specific order or size and these preferred dietary items may not be present in sufficient numbers to entice skinks into the edge to stay.

The following questions are investigated in this chapter:

- Do small skinks that take a wide range of prey items?

- Do small skinks show a preference for specific prey (taxa, size) in their diet?

- Does the distribution of prey alter between the core and edge?

- Does the demonstrated pattern of distribution affect skink distribution between the edge and core of small remnants?

**5.2. Methods.**

Selection of sites is presented in Chapter 2.

**5.2.1. Arthropod sampling.**

Arthropods were collected as described in Chapter 3.2.3, in addition individuals were measured and the results recorded.
5.2.2. Skink sampling

Skink data were collected as described in Chapter 3.2.1.

5.2.3. Lampropholis general diet.

Historical data (including information from remnants of the study area) were collected from the literature to determine the recorded prey *L. guichenoti* and *L. delicata*. This was done in preference to examining gut content of the skinks inhabiting these areas because animal ethic approval could not be obtained for this procedure.

The published data were used to identify preferred prey of the skinks. Previous researchers (Lunney *et al.*, 1989; Warner, 1995) had identified size preference in these species (both width and length), and these data were also drawn upon. The same size categorise used in these studies were utilised in this report, so that comparison could be made.

5.2.4. Data Analysis

Interactions between the taxa observed during the study were analysed using the BIOENV function within PRIMER, Version 5 (2001). This function allowed the generation of multiple correlations (using Spearman’s weighted rank correlation technique pattern) to observe a best fit explanation to distribution patterns of skinks with various combinations of prey species.
Other procedures used in the analysis of data are presented in Chapter 3.2.4.

5.3. Results.

5.3.1. Skink abundance and diversity.

Skink abundance and diversity results are presented in Chapter 3.3.2.

5.3.2. Lamprophis general diet.

Data compiled on the dietary intake of *L. guichenoti* (Table 5.1) and *L. delicata* (Table 5.2) indicated a range of prey items are consumed by these skinks. However, based on volume consumed, four orders of arthropods were shown to be preferred: Hymenoptera (particularly ants), Hemiptera, Araneae and Coleoptera. Of these only ants were reported as present in the gut of both species by all researchers.

Prey size was also shown to be important for both *Lamprophis* species. Warner (1995) identified that *L. guichenoti* took prey >10mm in width. Lunney, *et al.* (1989) observed that both species of *Lamprophis* consumed prey >20mm in length. Despite such differences both species took prey size preferentially within the range <1–3mm long, and 0-8mm wide. However, these skinks were most likely to take prey sized at <1-3mm long and 0-5mm wide.
Table 5.1. Data collected on dietary intake of *L. guichenoti*. The information is shown as percentage of volume of all guts observed in these skinks. Bolded areas indicate prey items common across all studies.

Reference

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acari</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Araneae</td>
<td>6.27</td>
<td>21</td>
<td>17.10</td>
<td>19.95</td>
<td>23.70</td>
</tr>
<tr>
<td>Blattodea</td>
<td>1.65</td>
<td>5</td>
<td>0</td>
<td>2.07</td>
<td>7.20</td>
</tr>
<tr>
<td>Chilopoda</td>
<td>0.57</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coleoptera</td>
<td>7.68</td>
<td>16</td>
<td>21.95</td>
<td>18.65</td>
<td>5.20</td>
</tr>
<tr>
<td>Adult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larva</td>
<td>4.83</td>
<td>0</td>
<td>4.90</td>
<td>1.30</td>
<td>3.10</td>
</tr>
<tr>
<td>Collembola</td>
<td>12.25</td>
<td>0</td>
<td>0</td>
<td>0.52</td>
<td>0</td>
</tr>
<tr>
<td>Dermaptera</td>
<td>0.29</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diptera</td>
<td>7.69</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unidentified</td>
<td>4.84</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>2.10</td>
</tr>
<tr>
<td>Flies</td>
<td>0</td>
<td>2</td>
<td>8.54</td>
<td>5.70</td>
<td>18.60</td>
</tr>
<tr>
<td>Mosquitos</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>Hemiptera</td>
<td>10.24</td>
<td>6</td>
<td>2.44</td>
<td>11.14</td>
<td>3.10</td>
</tr>
<tr>
<td>Hymenoptera</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ants</td>
<td>17.66</td>
<td>2</td>
<td>7.31</td>
<td>9.84</td>
<td>17.50</td>
</tr>
<tr>
<td>Wasps, Bees</td>
<td>2.83</td>
<td>0</td>
<td>1.21</td>
<td>3.63</td>
<td>3.10</td>
</tr>
<tr>
<td>Larva</td>
<td>0.57</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>Isopoda</td>
<td>0.57</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Isoptera</td>
<td>4.84</td>
<td>0</td>
<td>1.21</td>
<td>14.77</td>
<td>0</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>1.14</td>
<td>0</td>
<td>1.21</td>
<td>2.30</td>
<td>5.20</td>
</tr>
<tr>
<td>Adult</td>
<td>1.15</td>
<td>0</td>
<td>8.54</td>
<td>4.90</td>
<td>3.10</td>
</tr>
<tr>
<td>Larva</td>
<td>0.57</td>
<td>0</td>
<td>1.21</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mantodea</td>
<td>0</td>
<td>0</td>
<td>1.21</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mecoptera</td>
<td>0</td>
<td>0</td>
<td>1.21</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Odonata</td>
<td>0</td>
<td>0</td>
<td>1.21</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Adult</td>
<td>0</td>
<td>0</td>
<td>1.21</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Orthoptera</td>
<td>6.83</td>
<td>1</td>
<td>3.66</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>Trichoptera</td>
<td>0.28</td>
<td>0</td>
<td>2.44</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>4.28</td>
<td>6</td>
<td>13.48</td>
<td>5.18</td>
<td>1.00</td>
</tr>
<tr>
<td>Unidentified</td>
<td>2.01</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. of guts sampled</td>
<td>104</td>
<td>56</td>
<td>Unknown</td>
<td>90</td>
<td>73</td>
</tr>
</tbody>
</table>
Table 5.2. Data collected on dietary intake of *L. delicata*. The information is shown as a percentage of volume of all guts observed in these skinks. The * indicates that while prey items where observed no quantitative data were available. Bolded areas indicate prey items common across all studies.

Reference

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acari</td>
<td>3.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Araneae</td>
<td>6.4</td>
<td>*</td>
<td>57.2</td>
<td>10.1</td>
<td>15.7</td>
<td></td>
</tr>
<tr>
<td>Blattodea</td>
<td>1.8</td>
<td>0</td>
<td>0.4</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coleoptera</td>
<td></td>
<td>Adult</td>
<td>6.8</td>
<td>*</td>
<td>14.3</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Larva</td>
<td>3.2</td>
<td>0</td>
<td>3.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Collombola</td>
<td></td>
<td></td>
<td>9.1</td>
<td>0</td>
<td>4.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Dermaptera</td>
<td></td>
<td></td>
<td>0.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diptera</td>
<td></td>
<td>Unidentified</td>
<td>10.9</td>
<td>0</td>
<td>0</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flies</td>
<td>0</td>
<td>0</td>
<td>11.8</td>
<td>21.7</td>
</tr>
<tr>
<td>Hemiptera</td>
<td></td>
<td>Unidentified</td>
<td>14.1</td>
<td>*</td>
<td>0</td>
<td>11.4</td>
</tr>
<tr>
<td>Hymenoptera</td>
<td></td>
<td>Unidentified</td>
<td>*</td>
<td>6.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ants</td>
<td></td>
<td>*</td>
<td>6.8</td>
<td>*</td>
<td>28.5</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wasps, Bees</td>
<td>0</td>
<td>0</td>
<td>6.1</td>
<td>4.8</td>
</tr>
<tr>
<td>Isopoda</td>
<td></td>
<td></td>
<td>3.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Isoptera</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>27.6</td>
<td>0</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td></td>
<td>Adult</td>
<td>2.3</td>
<td>0</td>
<td>2.6</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Larva</td>
<td>2.7</td>
<td>0</td>
<td>3.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Orthoptera</td>
<td></td>
<td></td>
<td>4.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pscoptera</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.2</td>
</tr>
<tr>
<td>Trichoptera</td>
<td></td>
<td></td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td>13.6</td>
<td>0</td>
<td>4.8</td>
<td>3.6</td>
</tr>
<tr>
<td>No. of guts sampled</td>
<td>Unknown</td>
<td>99</td>
<td>7</td>
<td>8</td>
<td>73</td>
<td>49</td>
</tr>
</tbody>
</table>

5.3.3. Overall abundance and diversity of prey – size and order.

From the 22 taxa encountered (see Table 3.1), 16 were known *Lampropholis* dietary items (Figure 5.1 and 5.3). Within these taxa 3,184 individuals (1,765 edge, 1,419 core) were collected across the size range <1-10mm width and 0->20mm length (Figure 5.2).

Overall, edge and core sites demonstrated a high degree of similarly in terms of arthropod abundance and diversity (R = 0.188, P = 0.2; Figure 5.4). Edge (average
of 78.2%) and core (averaged 76.2%) areas both showed equivalent similarity within habitat type.

The rank-order of abundance (Figure 5.5) showed that numbers differed between edge and core. Hymenoptera (ants) were most abundant on edges, while Araneae (spiders) were in greatest abundance in core habitats, although only ant abundance was significantly different between the edge and core areas (P > 0.022; Table 5.3). Overall the abundance did not differ significantly except for ants, other Hymenoptera (P > 0.040) and Blattodea (P > 0.24). The rank abundance did not deviate from the trend line (Figure 5.5).

Table 5.3. Mean, standard deviation and t-test (* donates significance at 0.05) of the total number of arthropods collected and were determined to match the dietary size range consumed by the two *Lampropholis* skinks, encountered across all the edge and core sites in peri-urban north-western Sydney, 2001. Included in table is species habitat niche as either terrestrial (T), aerial/arboreal (A) or aquatic (W).

<table>
<thead>
<tr>
<th>Class</th>
<th>Order</th>
<th>Niche</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T Value (d.f. 6)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arachnida</td>
<td>Acari</td>
<td>T</td>
<td>7.8</td>
<td>11.70</td>
<td>1.8</td>
<td>0.50</td>
<td>1.025</td>
<td>0.345</td>
</tr>
<tr>
<td></td>
<td>Araneae</td>
<td>T/A</td>
<td>79.0</td>
<td>21.71</td>
<td>71.3</td>
<td>27.83</td>
<td>0.439</td>
<td>0.676</td>
</tr>
<tr>
<td></td>
<td>Isopoda</td>
<td>T</td>
<td>0.5</td>
<td>0.58</td>
<td>15.3</td>
<td>3.00</td>
<td>0.121</td>
<td>0.908</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T</td>
<td>61.5</td>
<td>42.46</td>
<td>57.8</td>
<td>45.14</td>
<td>0.121</td>
<td>0.908</td>
</tr>
<tr>
<td></td>
<td>Blattodea</td>
<td>T/A</td>
<td>2.0</td>
<td>0.82</td>
<td>0.5</td>
<td>0.58</td>
<td>0.121</td>
<td>0.908</td>
</tr>
<tr>
<td></td>
<td>Coleoptera</td>
<td>T</td>
<td>22.5</td>
<td>18.23</td>
<td>26.5</td>
<td>16.52</td>
<td>0.256</td>
<td>0.756</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T</td>
<td>3.3</td>
<td>1.71</td>
<td>3.8</td>
<td>3.59</td>
<td>0.251</td>
<td>0.810</td>
</tr>
<tr>
<td></td>
<td>Coleoptera Larva</td>
<td>T/W</td>
<td>14.0</td>
<td>28.00</td>
<td>1.3</td>
<td>1.50</td>
<td>0.909</td>
<td>0.398</td>
</tr>
<tr>
<td></td>
<td>Diptera</td>
<td>A</td>
<td>77.5</td>
<td>22.49</td>
<td>64.5</td>
<td>36.10</td>
<td>0.611</td>
<td>0.563</td>
</tr>
<tr>
<td></td>
<td>Diptera Larva</td>
<td>T/W</td>
<td>14.0</td>
<td>28.00</td>
<td>1.3</td>
<td>1.50</td>
<td>0.909</td>
<td>0.398</td>
</tr>
<tr>
<td></td>
<td>Hemiptera</td>
<td>A</td>
<td>24.3</td>
<td>7.37</td>
<td>28.5</td>
<td>15.07</td>
<td>0.507</td>
<td>0.630</td>
</tr>
<tr>
<td></td>
<td>Hymenoptera ants</td>
<td>T</td>
<td>118.8</td>
<td>41.63</td>
<td>52.5</td>
<td>11.96</td>
<td>3.059</td>
<td>0.022   *</td>
</tr>
<tr>
<td></td>
<td>Hymenoptera other</td>
<td>A</td>
<td>2.3</td>
<td>0.957</td>
<td>1.0</td>
<td>0.00</td>
<td>2.611</td>
<td>0.040   *</td>
</tr>
<tr>
<td></td>
<td>Isoptera</td>
<td>T</td>
<td>0.0</td>
<td>0.00</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lepidoptera</td>
<td>A</td>
<td>4.8</td>
<td>1.71</td>
<td>6.3</td>
<td>4.35</td>
<td>0.642</td>
<td>0.544</td>
</tr>
<tr>
<td></td>
<td>Lepidoptera Larva</td>
<td>A</td>
<td>7.8</td>
<td>5.62</td>
<td>27.0</td>
<td>21.21</td>
<td>1.754</td>
<td>0.130</td>
</tr>
<tr>
<td></td>
<td>Odonata</td>
<td>A</td>
<td>0.5</td>
<td>0.58</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Orthoptera</td>
<td>T</td>
<td>11.8</td>
<td>11.59</td>
<td>8.8</td>
<td>6.80</td>
<td>0.447</td>
<td>0.671</td>
</tr>
<tr>
<td></td>
<td>Pscooptera</td>
<td>T</td>
<td>2.0</td>
<td>4.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5.1. Total number of individuals (within order groups) of arthropods consistent with the dietary preferences of both *L. guichenoti* and *L. delicata* encountered across all edge (■) and core (●) sites in peri-urban north-western Sydney, 2001.
Figure 5.2. The total number of arthropods collected across all edge (■) and core (▲) sites in peri-urban north-western Sydney, and within each size category (width and length) of *L. guichenoti* and *L. delicata* prey consumed.
Figure 5.3. Mean number (S.E. and S.D.) of arthropods consistent with *L. guichenoti* and *L. delicata* dietary items encountered across all edge (■) and core (■) sites in peri-urban north-western Sydney, 2001.

Figure 5.4. MDS plots (derived from Bray-Curtis similarity) based on arthropod (identified as skink dietary items) abundance and diversity, collected from the 4 edge (■) and 4 core (▲) sites. Edge sites were similar as a group on average 78.2%. Core sites averaged a 76.2% similarity. There was similarity between edge and core sites (R = 0.188, P = 0.2).
<table>
<thead>
<tr>
<th>Species</th>
<th>Rank-edge</th>
<th>Rank-core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hymenoptera - ants</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Araneae</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Diptera</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Collembola</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Hemiptera</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Coleoptera</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Diptera Larva</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Orthoptera</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Acari</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Lepidoptera Larva</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Coleoptera Larva</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Hymenoptera - other</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Blattodea</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Psocoptera</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Mantodea</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Isopod</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Odonata</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>Chilopoda</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>Isoptera</td>
<td>20</td>
<td>17</td>
</tr>
</tbody>
</table>

Figure 5.5. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) in peri-urban north-western Sydney, 2001, for arthropods consumed by *L. guichenoti* and *L. delicata*. Plotted lines are linear trend-lines (edge, $R^2 = 0.99$; core, $R^2 = 0.97$).
5.3.4. Common dietary items - abundance, diversity and size.

Of the total number of invertebrates collected 2,603 individuals representing 16 taxa (1,515 edge, 1,088 core; Figure 5.6) were encountered within the size range of prey of the two Lampropholis species (Figure 5.7).

Overall, edge and core sites demonstrated a high degree of similarly in terms of arthropod abundance and diversity (R = 0.09, P = 0.229; Figure 5.8). Edge areas were similar to each other on average of 82%, while core areas similarity averaged 82.9%.

The rank-order of abundance demonstrated that the species numbers differed between edge and core. However, there was no deviation from the trend lines in either habitat site (Figure 5.9). Hymenoptera (ants) were most abundant on edges, while Araneae (spiders) where in greatest abundance in core habitats.

Spearman’s rank correlation test indicated that the combination of Hymenoptera (other than ants), Mantodea and Orthoptera abundance in the core and edge best explained the distribution of the skinks (P = 0.752; Table 5.4).

Abundance based on size parameters indicated that the majority of prey available, both in the edge and core, measured between 1-2mm wide by 5mm long. The highest abundance occurred within core areas (Figure 5.10). Despite this none of the commonly sized prey groups were significantly different between the core and edge.
areas. Rank abundance, based on size range, was the same for both core and edge, although slight variations occurred from the trend lines (Figure 5.11).

Spearman’s test indicated a moderate correlation between one size group (1-2mm wide and 3-5mm long) and skink distribution (P = 0.584). The strongest correlation occurred between this group and arthropods within the 2-3mm wide and 3-5mm long category (P = 0.744; Table 5.5).

![Figure 5.6. Mean (S.E. and S.D.) of arthropod abundance consistent with L. guichenoti and L. delicata dietary items and also match the preferred size range, encountered across all edge (■) and core (■) sites in peri-urban north-western Sydney, 2001.](image-url)
Table 5.4. Spearman’s rank correlation, conducted on various combinations of the 19 arthropod groups with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001

<table>
<thead>
<tr>
<th>P Value</th>
<th>Acari</th>
<th>Araneae</th>
<th>Blattodea</th>
<th>Coleoptera</th>
<th>Coleoptera Larva</th>
<th>Diptera</th>
<th>Diptera Larva</th>
<th>Hymenoptera ants</th>
<th>Hymenoptera other</th>
<th>Isopoda</th>
<th>Isopoda</th>
<th>Lepidoptera</th>
<th>Lepidoptera Larva</th>
<th>Mantodea</th>
<th>Odonata</th>
<th>Orthoptera</th>
<th>Pscoptera</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0.568</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 0.666</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 0.752</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 0.748</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 0.744</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 0.733</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 0.709</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 0.703</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 0.657</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10 0.657</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>11 0.564</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>12 0.508</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>13 0.449</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>14 0.363</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>15 0.267</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>16 0.202</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>17 0.147</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>18 0.036</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>19 -0.050</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Figure 5.7. Number of arthropods and orders that have been reported to be consumed by *L. guichenoti* and *L. delicata* and are within the most commonly consumed size range, encountered across all edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, 2001.

Figure 5.8. MDS plots (derived from Bray-Curtis similarity) based on arthropod abundance and diversity (and overlapping prey size preference), collected from the 4 edge (■) and 4 core sites (▲). Edge sites were similar as a group (average 82%). Core sites averaged 82.9% similarity. There was similarity between edge and core sites (*R* = 0.09, *P* = 0.229).
Figure 5.9. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001, for arthropods within the preferred size range (by order) consumed by *L. guichenoti* and *L. delicata*. Plotted lines are linear trend-lines (edge, $R^2 = 0.99$; core, $R^2 = 0.96$).
5.3.5. Abundance of preferred prey – size and order.

Previous data based on size of prey (Lunney et al., 1989; Warner, 1995) indicated that the most commonly consumed prey by both Lampropholis species measured between 1-2mm wide by 3-5mm long. Examination of prey available in this size range indicated 989 individuals, representing 9 taxa (558 edge and 431 core; Figure 5.11) were encountered (Figure 5.12). Rank order of these taxa indicated some variation between core and edge (Figure 5.13). However, none of the orders differed significantly in their abundance between the core and edge of these small remnants (Table 5.6).
Overall, edge and core sites demonstrated a high degree of similarly in terms of arthropod abundance and diversity ($R = 0.052, P = 0.686$; Figure 5.14). Core sites (83.7%) displayed a slightly greater degree of similarity compared to edge areas (74.3%).

Spearman analyses indicated that the presence of no one order explained the distribution of skinks throughout the core or edge. However, a combination of six taxa correlated the strongest with skink distribution between these areas ($P = 0.658$; Table 5.7).

**Table 5.5.** Spearman’s rank correlation, conducted on various combinations of the 9 arthropod size groups with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney 2001.
Figure 5.11. Rank abundance curves (and corresponding size) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001, for arthropods consumed by *L. guichenoti* and *L. delicata*. Plotted lines are linear trend-lines (edge, $R^2 = 0.923$; core, $R^2 = 0.923$).
Figure 5.12. Mean (S.E. and S.D.) of the total number of arthropods within the preferred size range consumed by *L. guichenoti* and *L. delicata*, encountered across all edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, 2001.

Table 5.6. Mean, standard deviation and t-test of the total number of arthropods (within the most commonly consumed prey size) encountered across the edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001. Included in table is species habitat niche as either terrestrial (T), aerial/arboreal (A) or aquatic (W).

<table>
<thead>
<tr>
<th>Class</th>
<th>Order</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T value (d.f. 6)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arachnida</td>
<td>Acari</td>
<td>2.8</td>
<td>5.50</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Araneae</td>
<td>43.3</td>
<td>15.41</td>
<td>43.0</td>
<td>13.09</td>
<td>0.025</td>
<td>0.981</td>
</tr>
<tr>
<td></td>
<td>Coleoptera</td>
<td>8.3</td>
<td>8.62</td>
<td>5.8</td>
<td>3.30</td>
<td>0.542</td>
<td>0.607</td>
</tr>
<tr>
<td></td>
<td>Coleoptera</td>
<td>2.8</td>
<td>2.22</td>
<td>3.3</td>
<td>0.96</td>
<td>0.414</td>
<td>0.693</td>
</tr>
<tr>
<td>Insecta</td>
<td>Coleoptera</td>
<td>0.8</td>
<td>0.96</td>
<td>1.5</td>
<td>1.29</td>
<td>0.933</td>
<td>0.387</td>
</tr>
<tr>
<td></td>
<td>Larva</td>
<td>0.8</td>
<td>0.96</td>
<td>1.5</td>
<td>1.29</td>
<td>0.933</td>
<td>0.387</td>
</tr>
<tr>
<td></td>
<td>Diptera</td>
<td>31.8</td>
<td>16.09</td>
<td>19.3</td>
<td>8.42</td>
<td>1.377</td>
<td>0.218</td>
</tr>
<tr>
<td></td>
<td>Hemiptera</td>
<td>10.3</td>
<td>2.63</td>
<td>12.8</td>
<td>6.35</td>
<td>0.681</td>
<td>0.521</td>
</tr>
<tr>
<td></td>
<td>Hymenoptera</td>
<td>43.3</td>
<td>36.62</td>
<td>12.8</td>
<td>6.68</td>
<td>0.968</td>
<td>0.371</td>
</tr>
<tr>
<td></td>
<td>Hymenoptera</td>
<td>1.0</td>
<td>0.82</td>
<td>1.0</td>
<td>0.00</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>other</td>
<td>1.0</td>
<td>0.82</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lepidoptera</td>
<td>3.5</td>
<td>3.87</td>
<td>2.8</td>
<td>3.59</td>
<td>0.284</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Orthoptera</td>
<td>3.5</td>
<td>3.87</td>
<td>2.8</td>
<td>3.59</td>
<td>0.284</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Figure 5.13. Number of arthropod individuals, in order group, most commonly consumed by *L. guichenoti* and *L. delicata*, encountered across all edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, 2001.
Figure 5.14. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) in of woodland remnants -urban north-western Sydney, 2001, for arthropods within the commonly taken size range by *L. guichenoti* and *L. delicata*. Plotted lines are linear trend.
Figure 5.15. MDS plots (derived from Bray-Curtis similarity) based on arthropod abundance and diversity (within the most commonly consumed prey size), collected from the 4 edge (■) and 4 core sites (▲). Edge sites were similar as a group on average 74.3%. Core sites averaged 83.7% similarity. There was similarity between edge and core sites ($R = 0.052, P = 0.686$).

Table 5.7. Spearman’s rank correlation, conducted on various combinations of the 11 arthropod groups (determined by skink dietary preference in both consummation and size) with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney.2001

<table>
<thead>
<tr>
<th>P Value</th>
<th>Acari</th>
<th>Araneae</th>
<th>Coleoptera</th>
<th>Coleoptera Larva</th>
<th>Collembola</th>
<th>Diptera</th>
<th>Hemiptera</th>
<th>Hymenoptera ants</th>
<th>Hymenoptera other</th>
<th>Lepidoptera</th>
<th>Orthoptera</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.444</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.549</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.570</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.602</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.637</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.658</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.615</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.568</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>9</td>
<td>0.508</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10</td>
<td>0.430</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>11</td>
<td>0.371</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
5.4. Discussion.

Both *L. guichenoti* and *L. delicata* take a wide range of prey, and show no clear affinity to a specific taxonomic order. Although there is some variation within the volume of prey consumed from among the dietary items identified, the consensus indicates that the two *Lampropholis* species have a generalist diet (Belmont, 1977; Crome, 1981; Webb, 1983; Lunney *et al*., 1991; Warner, 1995). Although *L. guichenoti* were previously reported to consume plant material and slough (believed to be ingested accidentally during moultng; Crome 1981; Lunney, *et al*. 1989; Brown 1991), both species are predominately insectivorous.

Previous researchers (eg. Belmont, 1977; Crome, 1981; Simbotwe, 1985a; Lunney *et al*., 1989; Warner, 1995) reported that *L. guichenoti* consumed three main groups of arthropods, ants, adult beetles and spiders. The only taxon that was reported in all analyses of *L. delicata* diet was ants (Rose, 1974; Belmont, 1977; Crome, 1981; Webb, 1983; Lunney *et al*., 1989; Warner, 1995). However, all authors, except Rose (1974), observed that *L. delicata* also had consistently high volumes of spiders and beetles in their stomach. It is likely that these also are a substantial component of their diet.

Of the three taxonomic groups widely consumed (beetles, ants and spiders), beetles averaged a larger body size than the other two, and have harder exoskeletons. Beetles, both larvae and adult, also feature in the diet of a range of lizards, for example, *Chalcides ocellatus* (Grimmond *et al*., 1994), *Podarcis melisellensis* (Verwaijen *et al*., 2002) *Xenosaurus grandis* (Ballinger *et al*., 1995) and *Eumeces*
obsoletus (Hall, 1972). This is despite of the fact that handling time for both the adult and larvae consumes greater energy for small skinks in terms of capturing and eating them than for larger animals (Grimmond et al., 1994). There is therefore, a trade-off in terms of the energy cost. For example, Grimmond, et al. (1994) observed that the Egyptian small skink *Chalcides ocellatus* utilised 50% more energy crushing and swallowing beetles than eating softer bodied animals, but assimilated no more than 1% in energy spent. They concluded that beetles were probably targeted due to their size since they needed only one beetle capture to reach satiation compared to several smaller animals. It has been hypothesised that sit-and-wait foragers are more vulnerable to predation while adopting this foraging strategy and, therefore, would be more circumspect in prey selection. The capture and consumption of one large item would expose them to less chance of predation than prolonged exposure waiting for several smaller prey items (Pough & Andrews, 1985; Andrews et al., 1987). Both *L. delicata* and *L. guichenoti* adopt different strategies for capturing their prey, including sit and wait ambush, as well as active foraging techniques (Lunney et al., 1989), and this could go to some way to explain why fewer beetles were found in the stomach contents of both species than ants.

Ants have been reported in the diet of *C. plagioccephalus* (Pianka, 1986), *C. virgatus* (Greer & Jefferys, 2001), *Ct. brooksi*, (Pianka, 1986), *Ct. pianka* (Pianka, 1986; James, 1991) *Moloch horridus* (Abensperg-Traun & Steven, 1997) and *Norpos humilis* (Vitt & Zani, 1998). The volume of ants taken in the diet of actively foraging skinks (such as the two *Lampropholis* species) is often relatively high (Abensperg-Traun & Steven, 1997). However, given that ants have limited nutritional value, and higher ratio of indigestible exoskeleton compared to fat and
protein, it would be expected that ants are taken more due to high encounter rates than as a preferred prey item (Griffiths & Simpson, 1966). Large quantities of ants may be consumed by predatory lizards, simply because of ant behaviour. Many ants, particularly worker castes, move on mass in trails, as well as living in large nests. It would be easy, therefore, for a skink to take large quantities of ants before their defensive mechanisms engaged (Greer & Jefferys, 2001). Lack of defence has also been suggested for some skinks (e.g. *C. virgatus*) preferentially selection of ant castes (Greer & Jefferys, 2001). However, alates contain higher fat levels than adults which could also attract skink predation of them (Redford & Dorea, 1984).

Preference for one cohort over another has been demonstrated in other animals, such as the Norway rat (*R. norvegicus*). In marsh areas they consume only juvenile diamond terrapins (*Malaclemys terrapin*; Draud *et al.*, 2004. Although the authors did not speculate about why rats selected juvenile terrapins, they may be taken as they emerged from the nest, when they would have lower defensive mechanisms (i.e. softer, less dense shells) or they may carry a yolk sac which would provide high levels of fat than older foraging animals.

If the two *Lampropholis* species were preferentially hunting ants, it would be expected that they would be in higher numbers in edge areas because ant abundance was higher in edges compared to interior areas. However, both skinks species were in lower numbers in edges compared to core areas and thus the presence of ants does not account for the differences in skink abundances in the two areas.
Spiders also feature in the diet of many of the reptiles mentioned above, and in the
diet of others including *Hemiergis decresiensis* (Crome, 1981), *Ameiva amevia,*
*Kentropyx pelviceps* and *K. altamazonica* (Vitt *et al.*, 2000). The prevalence of
arthropods within lizard diets is correlated with higher nutritional value and high
encounter rates (Poulin & Lefebvre, 1996). Ants, spiders and beetles inhabit areas
commonly utilised by *L. delicata* and *L. guichenoti,* for example, leaf litter and
ground cover vegetation (Simbotwe, 1985a; Molnar *et al.*, 2001). Encounter rates
with these insects would be, therefore, expected to be higher than with arboreal or
aerial taxa. This may explain why they are common in these skinks’ diet.

Most predators forage for palatable prey with relatively high encounter rates, that are
easy to handle and which will allow satiation levels to be reached efficiently (Pyke,
1984; Wourms & Wasserman, 1985). The *Lampropholis* skinks are not expected to
be different. However, there may be a link between what ants, spiders and beetles
consume and their relative preference as prey items for *Lampropholis* skinks. Prey
that consumes high nutrient food items may be more attractive to their predators than
those consuming less nutritious prey. For example, the side-blotched lizard (*Uta
stansburiana*), selected relatively larger numbers of arthropods that consumed algae
than those that did not. The difference was assumed to be due to the high nutritional
value gained from the algae eating arthropods (Barrett *et al.*, 2005).

*Lampropholis delicata* and *L. guichenoti* have been considered generalists and
opportunistic with respect to prey selection (as per Cox, 1969; Simbotwe, 1985b;
Brown, 1991; Lunney *et al.*, 1991). However, they may be more selective than
previously reported. For example, arthropods not previously recorded as being taken
by either *Lampropholis* species were encountered in both edge and core areas (e.g. woodlice (Isopoda) and silverfish (Thysanura) were within the size parameters of dietary intake and could have been encountered by these skinks. Some potential prey were soft bodied and would be expected to be taken by skinks because less energy would be expended in consuming them compared to many of the species taken. Such soft body prey may be consumed but were not present in their stomach because they are more easily and quickly digested. Differential digestion rates can easily cause a misrepresentation of dietary items (Hyslop, 1980). Their absence could also be due to them not being recognised as potential prey, or they may be unpalatable, or simply due to low encounter rates.

Although not identified as part of *L. delicata* or *L. guichenoti* diet, soft bodied arthropods may be taken in times of hardship. Altering behaviour due to changes in prey availability and adverse ecological conditions has been reported in other skinks. For example, Prairie skink *Eumeces septemrionalis* abundance declined in proportion to decreasing arthropod numbers, post burn off in old fields (Pitt, 2001). Brown iguanas *Ctenosaura pectinata* were also observed to consume more plant material during drought when fewer arthropod prey were available (Cooper & Lemos-Espinal, 2001). During sampling for this study, the area suffered drought. There may have been a switch in diet. Under these circumstances both skinks could have been less selective in their foraging behaviour, and prey may have been taken outside of the normal array. Reduced availability of prey may also have effected their distribution throughout the remnants, as the skinks may alter both foraging patterns and habitats in search of food.
Diet may also change with different life stages. For example, juvenile *A. aeneus*, restricted their diet to only six arthropod taxa, while adults took a wider selection. Prey differentiation can also occur between the sexes of the same lizard species. For example, the grand skink *Oligosoma grande* displayed variation in prey selection between the sexes. Males were more likely to take larger and faster moving prey than the females, who preferred weak-flying arthropods and fruit (Eifler & Eifler, 1999). Prey discrimination between sexes of lizards has been linked to variations in head size (Verwaijen *et al.*, 2002), and changes in foraging patterns (Eifler & Eifler, 1999). No such sexual dimorphism has been identified in either *L. delicata* or *L. guichenoti* and there is no mention of dietary differentiation between juveniles, sub-adults or adults. However, changes in prey selection between stages could explain why Anderson and Burgin (2002) encountered niche separation between juveniles and adults (utilise core areas) and sub-adults (encountered more often in the perimeter).

There is other evidence that suggest that these two *Lampropholis* species may not be as opportunistic as previously assumed. Data collected by Lunney, *et al.* (1989) and Warner (1995) suggested that these skinks have a very distinct affinity for taking prey of a specific size range.

Size preference is dependent on handling capability, and gap width. For example, *C. virgatus* have been reported to prefer prey <10mm in length (Webb, 1983) while *H. decresiensis* (a skink with SVL of 16cm) have been shown to favour prey around 8mm (Crome, 1981). The rainbow lizard of Kenya (SVL 10 –16 cm) prefers prey sized between 6-8mm in length. *Lampropholis guichenoti* and *L. delicata*, have been
recorded to take prey in excess of 20mm in length (Lunney et al., 1989) and 10 mm in width (Warner 1995). Although, both more commonly select prey within a much smaller size band, i.e. ≤1-3mm in width and 0-8mm long, with greater preference given to prey 1-2mm wide by 3-5mm long.

Statistically, core and edge areas appear to be similar in terms of abundance and diversity within both the commonly taken prey and preferred prey sizes. However, there were some subtle differences between the areas in terms of rank abundance and prey combinations which could potentially effect *Lampropholis* distribution in the remnants.

Among the most commonly taken prey size range, the strongest correlation between skink distribution and taxon abundance occurred with Hymenoptera – other (bees and wasps), Mantodea (mantids) and Orthoptera (crickets and grasshoppers). These three groups do not feature strongly (in terms of volume consumed) within the diet of either *L. delicata* or *L. guichenoti*, nor were they encountered in large numbers. They would, therefore, not necessarily sustain these skinks into the edge (where the majority of individuals in these groups were encountered) and would then be expected to correlate highest with skinks distribution. However, when the abundance and diversity of prey is examined in relation to preferred prey size (i.e. 1-2mm wide by 3-5mm long), a wide range of arthropod taxonomic groups are correlated moderately strongly with skink distribution (see Table 5.7). Among these are two of the most common arthropods found in both *L. delicata* and *L. guichenoti* diets; beetles and ants.
The data also indicated that the greater the number of taxonomic groups inhabiting both core and edge areas, the weaker the link between them and the reported distribution of the *Lampropholis* skinks. That is, the more prey available to these skinks, the more difficult it is to explain why they avoid edges, in preference of core areas.

It would be expected that as edges have the greater abundance prey overall (although not statistically significant), there would be a tendency for these skinks would be able to forage successfully within this habitat type. Certainly this is the case for other animals. For example, the red fox *Vulpes vulpes* was shown to move into farmland/forest edges attracted by avian nest prey (Storch *et al.*, 2005). Racoons *Procyn lotor* were attracted to both water and wood edges due solely to the increase of prey availability when painted turtles *Chrysemys picta* were nesting (Kolbe & Janzen, 2002). A lack of general prey numbers does not therefore explain lower numbers of small skinks within the edges of the study remnants.

Abundance of prey was greatest (within both habitat types) among those arthropods sized in the preferred range. There tended to be a greater number of prey in edge areas compared to core but the relative distribution of arthropods did not differ between core and edge. These observations further indicate that these habitat groups offer adequate preferred prey.

When arthropod abundance was examined based on *Lampropholis* optimum size preferences, the variety of taxonomic groups available almost halved (11 from 20). These 11 taxa were approximately equally distributed between edge and core. There
was, therefore, no apparent reason for differences in distribution of skinks based on prey size preference.

In this case there appears to be no real edge effect influencing prey abundance and availability. It is concluded, therefore, that skink distribution was influenced by factors other than prey. Arthropod presence is likely to attract additional predators other than skinks. Many birds may be insectivorous or they may supplement their diet by consuming skinks (Barker & Vestjens, 1984b, a; Marchant & Higgins, 1990). This could create an interspecific competitive relationship between birds and skinks. Such an interaction between these two could influence the distribution of skinks in edge and core areas.
Chapter 6: Competition for Resources between Avian and Small Skinks.

6.1. Introduction.

Survival of any species depends on their ability to exploit the limited resources available (Schleuter & Eckmann, 2006). However, no species lives in isolation from another, and competition for the resources is an every day occurrence (Chase et al., 2002). How well a species copes in the face of competition can ultimately determine their longevity within a habitat (Morin, 1983).

The interaction between species, that is competition, has become a major focus of ecologists (Morris et al., 2000). In general terms, competition can manifest itself in two important ways. The first occurs when taxa utilising the same resources are equally affected by the other’s presence (symmetric competition), thereby no overriding ill effect occurs. Conversely, when one organism is effectively ‘out competed’ by another and the former is restricted in their use of resources, asymmetric competition occurs (Smith et al., 2004; Morris et al., 2000; Bonesi et al., 2004).

According to Keddy (2001) there are two criteria that are required before an asymmetrical or interspecific competitive relationship is formed. Firstly the taxa concerned must utilise the same resources and secondly, one of them must be able to exploit the resource at the expense of the other.
There have been numerous reports of such relationships. For example, in the Estosha National Park (Namibia), female elephants *Loxodonta africana*, excluded black rhinos *Diceros bocnnis*, from small fragments of suitable habitat, simply by being more aggressive in their use of the available resources (Berger & Cunningham, 1998). The parasitic gall mite *Phytoptus caricis* demonstrated a negative competitive effect on the smut fungus *Anthracoidea heterospora* in early infections of the common sedge *Carex nigra*, simply because of their ability to infect in larger numbers (Ingvarsson & Ericson, 2000).

There appears to be a link between interspecific competition and density differentials between the species involved (Morris *et al.*, 2000). When one species occupies an area in greater numbers than another, than the former is able to monopolise the resources available at the expense of the latter. For example, due to the more rapid and prolific reproductive rate of the introduced Cuban tree frog *Osteopilus septentrionalis*, their tadpoles were able to dominate the available resources in Florida. This equated to the reduction of growth rates in the tadpoles of the native green tree frog *Hyla cinerea* (Smith, 2005). The swamp rat *R. luteralus* and the eastern chestnut mouse *Pseudomys gracilicaudatus* co-occur in heathland regions of eastern Australia. The larger swamp rat dominates both wet and dry variations of the habitat, simply because of its size (Morris *et al.*, 2000).

The competitive edge has been linked to success as a predator for example, when taxa are more diverse in their prey selection, and/or has an ability to dominate superior foraging territories (Abrams, 1992). For example, many bird species , such
as noisy miner *M. melanocephala*, favour a wide selection of prey items including arthropods, and this puts them in competition with other animals, within the habitat, including skinks (O'Leary & Jones, 2006).

Given the complexity of lizard and bird interaction, studies of competition between the two are limited. From the data available, no interspecific competitive relationship could be established between these taxonomic groups (Adolph & Roughgarden, 1986; Hofer *et al.*, 2004). For example, Adolph and Roughgarden (1986) investigated the use of resources by birds and lizards in dry sclerophyll scrub. They determined that these taxa did not compete for food, but that their interaction was solely one of predator and prey. Hofer *et al.* (2004) suggested that birds and lizards adjusted their foraging patterns for arthropods, to avoid potential competition. However, these studies were undertaken in relatively undisturbed habitats where natural behaviour was not tested by habitat loss. The possible overlap of prey selection was also not investigated in either of these studies.

It has been widely documented that as urban environments are expanded, birds are facing survival issues due to loss of habitat and thus loss of foraging grounds (Recher *et al.*, 1993; Recher, 1996; Ford *et al.*, 2001; Major *et al.*, 2001; Mac Nally *et al.*, 2004; French *et al.*, 2005). As a result, birds forage in ever diminishing remnants in the landscape. Under these circumstances it would be inevitable that birds would come into closer proximity with other taxa, such as skinks, that normally forage in different niches or over a wider area. This would increase the risk of interspecific competitive relationships being established (Aguiar *et al.*, 2001). The extent of such
a relationship could put skinks at a disadvantage, as they are often vulnerable to predatory birds that may switch their attack from arthropods to skinks. As a result competition could force skinks to occupy habitat in lower numbers or ultimately cause them to abandon areas of conflict. This threat would be magnified in edge areas of remnants, where habitat loss is intensified and resources are likely to be limited. In this context the following question is investigated.

- Is there competition for resources between birds and small skinks in edge and core areas of remnant woodland?

- Does competition explain distribution of skinks in edge areas of the remnants?

6.2. Methods

Selection of sites is presented in Chapter 2.

6.2.1. Animal sampling

Skink (Chapter 3.21) and avian data (Chapter 3.2.2) were collected as described previously.

A literature search was undertaken to identify avian known to utilise similar resources to the skinks encountered in this study. These data collected for birds were used for comparison with skink data. Published research (McKilligan, 1984; Ford et al., 1988; Hughes et al., 1996; Todd, 1996; Cox & Bauer, 1997; Pell & Tidemann,
1997; Pizzey & Knight, 1997) also provided bird behavioural patterns that could have an impact on skink numbers.

### 6.2.2. Data Analysis

To determine seasonal differences, the seasonal abundance of both birds and skinks were analysed using a Chi square test. Other procedures used in the analysis are presented in Chapters 3.2.4 and 5.2.4.

### 6.3. Results

#### 6.3.1. Skink Abundance and Diversity

Skink abundance and diversity results are presented in Chapter 3.3.2.

#### 6.3.2. Seasonal skink abundance and diversity

There was no significant difference observed between the three seasons/core and edge abundance of skinks ($\chi^2 = 0.105$). Overall skink numbers were greatest overall during spring (Table 6.1), although there were more in edge areas during summer (Figure 6.1).

**Table 6.1.** Seasonal number of skinks encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney ($\chi^2 = 0.105$).

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge</td>
<td>45</td>
<td>59</td>
<td>20</td>
</tr>
<tr>
<td>Core</td>
<td>148</td>
<td>91</td>
<td>112</td>
</tr>
<tr>
<td>Total</td>
<td>193</td>
<td>150</td>
<td>121</td>
</tr>
</tbody>
</table>
6.3.3. Identification of Avian Competitors.

A total of 23 bird species were identified as being possible competitors with skinks for resources in the woodland remnants of the study. Of these eight have been reported as being aggressive and seven were considered to use noise in defence of their territory (Table 6.2.).
Table 6.2. List of potential avian competitors, their foraging behaviour (including niche) and other behaviour which could impact on skink numbers in edge and core areas of woodland remnants in peri-urban north-western Sydney. Included in table is species size: Large (L; >40cm), Medium (M; 20 – 40cm) and Small (S; <20cm), as well as whether they are endemic (E) or introduced (I). Other abbreviations used in the table include: Y – yes, N- No and S – sometimes.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name/s</th>
<th>Size</th>
<th>E/I</th>
<th>Foraging Numbers</th>
<th>Foraging Niche</th>
<th>Aggressive Y/N</th>
<th>Noisy Y/N/S</th>
<th>Comments</th>
<th>Reference:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthiza pyusilla</td>
<td>Brown thornbill</td>
<td>S</td>
<td>E</td>
<td>1 - &lt;5</td>
<td>Low branches</td>
<td>N</td>
<td>N</td>
<td>Fussily active</td>
<td>Recher et al., 1987; Pizzey &amp; Knight, 1997</td>
</tr>
<tr>
<td>Acridotheres tristis</td>
<td>Common myna</td>
<td>M</td>
<td>I</td>
<td>1 - &gt;10</td>
<td>Ground &amp; higher</td>
<td>Y</td>
<td>Y</td>
<td>Can utilise anthropogenic structures</td>
<td>Pell &amp; Tidemann, 1997; Pizzey &amp; Knight 1997</td>
</tr>
<tr>
<td>Ardea ibis</td>
<td>Cattle egret</td>
<td>L</td>
<td>I</td>
<td>&gt;10</td>
<td>Ground</td>
<td>N</td>
<td>N</td>
<td>Usually sort term occupants</td>
<td>McKilligan, 1984</td>
</tr>
<tr>
<td>Cacatuna galerita</td>
<td>Galah</td>
<td>L</td>
<td>E</td>
<td>2 - &gt;10</td>
<td>low leaves &amp; ground</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>Pizzey &amp; Knight 1997</td>
</tr>
<tr>
<td>Cacatuna roseicapilla</td>
<td>Sulphur crested cockatoo/white cockatoo</td>
<td>M</td>
<td>E</td>
<td>2 - &gt;10</td>
<td>low leaves &amp; ground</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>Pizzey &amp; Knight 1997</td>
</tr>
<tr>
<td>Calyptorhynchus funereus</td>
<td>Yellow-tailed black-cockatoo</td>
<td>L</td>
<td>E</td>
<td>2, 3 or &gt;10</td>
<td>Leaves, bark &amp; ground</td>
<td>N</td>
<td>Y</td>
<td></td>
<td>Pizzey &amp; Knight 1997</td>
</tr>
<tr>
<td>Coracina novaehollandiae</td>
<td>Black-faced cuckoo shrike</td>
<td>M</td>
<td>E</td>
<td>1 - &lt;5</td>
<td>Leaves</td>
<td>N</td>
<td>N</td>
<td></td>
<td>Ford et al., 1988</td>
</tr>
<tr>
<td>Corcorax melanorhamphos</td>
<td>White-winged chough</td>
<td>L</td>
<td>E</td>
<td>&gt;10</td>
<td>Ground</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td>Cox &amp; Bauer, 1997</td>
</tr>
<tr>
<td>Cormobates leucophaeus</td>
<td>White-throated treecreeper/woodpecker</td>
<td>S</td>
<td>E</td>
<td>1 - &lt;5</td>
<td>Leaves</td>
<td>N</td>
<td>N</td>
<td></td>
<td>Cox &amp; Bauer, 1997</td>
</tr>
<tr>
<td>Corvus coroneis</td>
<td>Australian raven/raven</td>
<td>L</td>
<td>E</td>
<td>1 - &lt;5</td>
<td>Snatch &amp; ground</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td>Pizzey &amp; Knight 1997</td>
</tr>
<tr>
<td>Cracticus torquatus</td>
<td>Grey butcherbird</td>
<td>M</td>
<td>E</td>
<td>1 - &lt;5</td>
<td>Snatch from ground</td>
<td>Y</td>
<td>S</td>
<td>Aggressive usually near nests</td>
<td>Pizzey &amp; Knight 1997</td>
</tr>
<tr>
<td>Dacelo novaeguineae</td>
<td>Laughing kookaburra/kookaburra</td>
<td>L</td>
<td>E</td>
<td>2 - &lt;5</td>
<td>Snatch from ground</td>
<td>Y</td>
<td>S</td>
<td>Aggressive in territorial groups/ utilise anthropogenic</td>
<td>Pizzey &amp; Knight 1997</td>
</tr>
<tr>
<td>Species Name</td>
<td>Common Name</td>
<td>Sex</td>
<td>Energetics</td>
<td>Activity</td>
<td>Foraging</td>
<td>Aggression</td>
<td>Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>----------------------</td>
<td>------</td>
<td>------------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Grallina cyanoleuca</em></td>
<td>Magpie lark/peewee</td>
<td>M</td>
<td>E</td>
<td>2 - &lt;10</td>
<td>Ground</td>
<td>Y</td>
<td>N</td>
<td>Ford et al., 1988</td>
<td></td>
</tr>
<tr>
<td><em>Gymnorhina tibicen</em></td>
<td>Australian magpie/magpie</td>
<td>L</td>
<td>E</td>
<td>2 - &gt;10</td>
<td>Ground</td>
<td>Y</td>
<td>Y</td>
<td>Hughes et al., 1996; Pizzey &amp; Knight, 1997</td>
<td></td>
</tr>
<tr>
<td><em>Hirundo nigriceps</em></td>
<td>Tree martin/tree swallow</td>
<td>S</td>
<td>E</td>
<td>5 - &gt;10</td>
<td>Air</td>
<td>N</td>
<td>N</td>
<td>Ford et al., 1988; Pizzey &amp; Knight, 1997</td>
<td></td>
</tr>
<tr>
<td><em>Neochnia temporalis</em></td>
<td>Red brow finch</td>
<td>S</td>
<td>E</td>
<td>2 - &lt;5</td>
<td>Leaves</td>
<td>N</td>
<td>N</td>
<td>Todd, 1996; Pizzey &amp; Knight 1997</td>
<td></td>
</tr>
<tr>
<td><em>Philemon corniculatus</em></td>
<td>Noisy friarbird/leatherhead</td>
<td>M</td>
<td>E</td>
<td>1 - &lt;10</td>
<td>High canopy</td>
<td>Y</td>
<td>Y</td>
<td>Ford et al., 1988; Pizzey &amp; Knight 1997</td>
<td></td>
</tr>
<tr>
<td><em>Platycercus eximius</em></td>
<td>Eastern rosella</td>
<td>M</td>
<td>E</td>
<td>2 - &lt;10</td>
<td>Snatch &amp; ground</td>
<td>N</td>
<td>Y</td>
<td>Pizzey &amp; Knight 1997</td>
<td></td>
</tr>
<tr>
<td><em>Rhipidura leucophrys</em></td>
<td>Willie wagtail</td>
<td>S</td>
<td>E</td>
<td>1 - &lt;5</td>
<td>Air &amp; ground</td>
<td>N</td>
<td>N</td>
<td>Ford et al., 1988; Pizzey &amp; Knight 1997</td>
<td></td>
</tr>
<tr>
<td><em>Rhipidura rufifrons</em></td>
<td>Rufous fantail</td>
<td>S</td>
<td>E</td>
<td>1-2</td>
<td>Air through undergrowth</td>
<td>N</td>
<td>N</td>
<td>Ford et al., 1988; Pizzey &amp; Knight 1997</td>
<td></td>
</tr>
<tr>
<td><em>Rhipidura fuliginosa</em></td>
<td>Grey fantail</td>
<td>S</td>
<td>E</td>
<td>1 - &lt;5</td>
<td>High canopy</td>
<td>N</td>
<td>N</td>
<td>Ford et al., 1988; Pizzey &amp; Knight 1997</td>
<td></td>
</tr>
<tr>
<td><em>Sturnis vulgaris</em></td>
<td>Common starling</td>
<td>M</td>
<td>I</td>
<td>1</td>
<td>Snatch &amp; ground</td>
<td>S</td>
<td>N</td>
<td>Pizzey &amp; Knight 1997</td>
<td></td>
</tr>
</tbody>
</table>
6.3.4. Avian Competitor Abundance and Diversity.

A total of 766 competitive birds, from 23 species, 409 in edge areas and 357 in core areas, were identified as possible competitors of small skinks (Figure 6.2; 6.3).

There was no similarity in competitive bird populations between edge and core sites ($R = 0.875, P = 0.029$). The within site test demonstrated that sites were almost equivalent in similarity based on abundance and diversity: edge group average 63.7%; core group average 60.3% (Figure 6.4).

Rank abundance demonstrated that avian presence closely followed the trend lines (Figure 6.5). The abundance and diversity of the species differed between the two habitat types, for example tree martins Hirundo nigricans, were not encountered in the edge, but were the 3rd most abundant species in the core. However of the 23 competitive species encountered only eight were present in sufficient numbers to allow analysis. Of these, two demonstrated a significant difference between core and edge; the grey butcherbird Cracticus torquatus, and the noisy miner Manorina melanocephala (Table 6.3).

Spearman analysis indicated that the presence of twelve avian species (Table 6.4) correlated the strongest with the distribution of skinks throughout the sites ($P = 0.537$). However, the combination of all competitive species had the least effect on skink distribution ($P = -0.111$; Table 6.4).
Figure 6.2. Total avian competitor abundance and diversity encountered across all edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, 2001/02
Figure 6.3. Mean number (S.E. and S.D.) of competitive birds encountered across all edge (■) and core (▲) sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

Figure 6.4. MDS plots (derived from Bray-Curtis similarity) based on avian competitor abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed a slightly greater degree of similarity as a group (average 63.7%). Core sites were less similar (average 60.3%). There is no similarity between edge and core sites of remnants ($R = 0.875, P = 0.029$).
Figure 6.5. Rank abundance curves (and corresponding orders) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001/02 for competitive avian species. Plotted lines are linear trend-lines.
Table 6.3. Mean, standard deviation and t-test (* donates significance at 0.05) of the competitive avian species, encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common Name</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T Value (d.f. 6)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthiza pyusilla</td>
<td>Brown thornbill</td>
<td>0.0</td>
<td>0.00</td>
<td>1.5</td>
<td>1.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acridotheres tristis</td>
<td>Common myna</td>
<td>7.0</td>
<td>3.16</td>
<td>10.0</td>
<td>10.42</td>
<td>0.551</td>
<td>0.602</td>
</tr>
<tr>
<td>Ardea ibis</td>
<td>Cattle egret</td>
<td>3.3</td>
<td>5.25</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cacatuna galera</td>
<td>Sulphur crested cockatoo</td>
<td>3.0</td>
<td>4.76</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cacatuna roseicapilla</td>
<td>Galah</td>
<td>5.0</td>
<td>4.97</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calyporhynchus funereus</td>
<td>Yellow-tailed back cockatoo</td>
<td>0.5</td>
<td>1.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coracina novaehollandiae</td>
<td>Black faced cuckoo shrike</td>
<td>1.8</td>
<td>2.06</td>
<td>4.0</td>
<td>3.27</td>
<td>1.165</td>
<td>0.288</td>
</tr>
<tr>
<td>Corcorax melanorhamphos</td>
<td>White-winged chough</td>
<td>14.0</td>
<td>15.10</td>
<td>14.3</td>
<td>6.40</td>
<td>0.030</td>
<td>0.977</td>
</tr>
<tr>
<td>Cymbobates leucophaeus</td>
<td>White throated treecreeper</td>
<td>0.0</td>
<td>0.00</td>
<td>0.3</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corvus coronides</td>
<td>Australian raven</td>
<td>14.5</td>
<td>11.09</td>
<td>7.5</td>
<td>1.91</td>
<td>1.244</td>
<td>0.260</td>
</tr>
<tr>
<td>Cricetis torquatus</td>
<td>Grey butcherbird</td>
<td><strong>8.5</strong></td>
<td><strong>3.70</strong></td>
<td><strong>1.3</strong></td>
<td><strong>0.96</strong></td>
<td><strong>3.797</strong></td>
<td><strong>0.009</strong></td>
</tr>
<tr>
<td>Dacelo novaeguineae</td>
<td>Laughing kookaburra</td>
<td>4.3</td>
<td>5.32</td>
<td>3.0</td>
<td>3.16</td>
<td>0.404</td>
<td>0.700</td>
</tr>
<tr>
<td>Grallina cyanoleuca</td>
<td>Magpie lark</td>
<td>1.0</td>
<td>2.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gymnorhina tibicen</td>
<td>Australian magpie</td>
<td>10.8</td>
<td>8.18</td>
<td>2.3</td>
<td>2.63</td>
<td>1.978</td>
<td>0.095</td>
</tr>
<tr>
<td>Hirundo nigricans</td>
<td>Tree martin</td>
<td>0.0</td>
<td>0.00</td>
<td>12.5</td>
<td>6.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manorina melanocephala</td>
<td>Noisy miner</td>
<td><strong>25.3</strong></td>
<td><strong>7.37</strong></td>
<td><strong>5.3</strong></td>
<td><strong>6.65</strong></td>
<td><strong>4.030</strong></td>
<td><strong>0.006</strong></td>
</tr>
<tr>
<td>Neochmia temporalis</td>
<td>Red browed finch</td>
<td>0.0</td>
<td>0.00</td>
<td>14.5</td>
<td>25.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philemon corniculatus</td>
<td>Noisy friarbird</td>
<td>0.0</td>
<td>0.00</td>
<td>3.8</td>
<td>7.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platycercus eximins</td>
<td>Eastern Rosella</td>
<td>3.0</td>
<td>3.83</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhipidura fuliginosa</td>
<td>Grey fantail</td>
<td>0.0</td>
<td>0.00</td>
<td>2.3</td>
<td>0.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhipidura leucophrys</td>
<td>Willie wagtail</td>
<td>0.0</td>
<td>1.00</td>
<td>3.0</td>
<td>2.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhipidura rufifrons</td>
<td>Rufous fantail</td>
<td>0.0</td>
<td>0.00</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sturnis vulgaris</td>
<td>Common starling</td>
<td>1.0</td>
<td>2.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6.4. Spearman’s rank correlation, conducted on various combinations of the 23 avian species with skink numbers. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001/02.

| P value | Dacelo novaeholland | Cracticus torquatus | Corvus melanoleucos | Coracina novaeholland | Corvidae | Acanthiza pyuilla | Calyptorhynchus funereus | Calyptorhynchus galerita | Coracina temporalis | Gymnorhina tibicen | Grallina cyanoleuca | Acrocephalus dasioides | Ardeidae | Rhipidura fuliginosa | Rhipidura leucophrys | Rhipidura rufifrons | Rhipidura leucophrys | Sturnus vulgaris | Manorina melanocephala | Manorina melanocephala | Manorina melanocephala | Manorina melanocephala | Manorina melanocephala | Manorina melanocephala | Manorina melanocephala | Manorina melanocephala |
|---------|---------------------|---------------------|---------------------|---------------------|---------|------------------|-----------------------|-----------------------|---------------------|------------------|------------------|-----------------------|---------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| 1       | 0.289               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 2       | 0.369               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 3       | 0.477               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 4       | 0.466               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 5       | 0.439               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 6       | 0.404               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 7       | 0.448               |                     |                     |                     |         | X                |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 8       | 0.511               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 9       | 0.516               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 10      | 0.424               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 11      | 0.368               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 12      | 0.537               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 13      | 0.527               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 14      | 0.482               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 15      | 0.441               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 16      | 0.398               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 17      | 0.359               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 18      | 0.288               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 19      | 0.237               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 20      | 0.195               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 21      | 0.102               |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 22      | -0.004              |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
| 23      | -0.111              |                     |                     |                     |         |                  |                       |                       |                     |                  |                  |                       |         |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |                  |
6.3.5. Avian Competitor Seasonal Abundance and Diversity.

There was no significant difference observed between the three seasons/core and edge abundance of competitive avian ($\chi^2 = 0.023$; Table 6.5). The number of individuals observed in remnants peaked in summer (Table 6.5). Fewer individuals were observed during autumn, but diversity was greater.

Seasonal variation between core and edge areas occurred in terms of both avian distribution and abundance (Figure 6.6). The variation in both species composition and numbers between the seasons made comparison between the three seasons difficult (Table 6.6). Only five species were encountered in sufficient numbers in one or two seasons to allow analysis. A significant difference between competitive birds in the edge and core of remnants was estimated in three species; Australian magpie *G. tibicen*, noisy miner and grey butcherbird. However, this was only observed during summer.

Table 6.5. Seasonal number of competitive avian encountered across all core and edge of woodland remnants in peri-urban north-western Sydney ($\chi^2 = 0.023$). The number of different species encountered is shown in brackets.

<table>
<thead>
<tr>
<th></th>
<th>Spring (12)</th>
<th>Summer (16)</th>
<th>Autumn (22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge</td>
<td>72</td>
<td>241</td>
<td>98</td>
</tr>
<tr>
<td>Core</td>
<td>74</td>
<td>130</td>
<td>148</td>
</tr>
<tr>
<td>Total</td>
<td>146</td>
<td>371</td>
<td>246</td>
</tr>
</tbody>
</table>
Figure 6.6. Mean number (S.E. and S.D.) of competitive avian for the seasons spring, autumn 2001 and summer 2002, encountered across all edge (■) and core (●) sites of woodland remnants in peri-urban north-western Sydney.
Table 6.6. Seasonal mean number, standard deviation and t-test (* donates significance at 0.05) of the competitive avian species, encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

<table>
<thead>
<tr>
<th>Species Name</th>
<th>SPR</th>
<th>SUM</th>
<th>AUT</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T Value (df. 6)</th>
<th>P value</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T Value (df. 6)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthiza pusilla</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.3</td>
<td>0.50</td>
<td>0.0</td>
<td>0.0</td>
<td>1.5</td>
<td>1.92</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Acridotheres tristis</td>
<td>1.5</td>
<td>0.58</td>
<td>3.0</td>
<td>2.45</td>
<td>1.192</td>
<td>0.278</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>1.00</td>
<td>3.5</td>
<td>5.67</td>
</tr>
<tr>
<td>Ardea ibis</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>1.3</td>
<td>1.50</td>
<td>0.0</td>
<td>0.00</td>
<td>1.0</td>
<td>1.00</td>
<td></td>
<td></td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cacatuna galerita</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>0.5</td>
<td>1.0</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Cacatuna roseicapilla</td>
<td>0.8</td>
<td>0.96</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td>1.3</td>
<td>2.50</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td>0.10</td>
</tr>
<tr>
<td>Calyptorhynchus funereus</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.00</td>
</tr>
<tr>
<td>Coracina novaehollandiae</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>1.8</td>
<td>2.06</td>
<td>1.8</td>
<td>1.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Corcorax melanorhamphos</td>
<td>6.0</td>
<td>4.76</td>
<td>5.8</td>
<td>1.71</td>
<td>0.989</td>
<td>0.924</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>1.92</td>
</tr>
<tr>
<td>Cormobates leucophaeus</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>0.0</td>
<td>0.00</td>
<td>0.3</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Corvus corax</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>13.3</td>
<td>11.95</td>
<td>7.5</td>
<td>1.91</td>
<td>0.950</td>
<td>0.379</td>
<td>0.5</td>
<td>1.00</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Cracticus torquatus</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td>5.8</td>
<td>1.708</td>
<td>1.3</td>
<td>0.96</td>
<td>4.60</td>
<td>0.004*</td>
<td>7.3</td>
<td>4.57</td>
<td>6.0</td>
</tr>
<tr>
<td>Dacelo novaeguineae</td>
<td>0.5</td>
<td>0.58</td>
<td>0.8</td>
<td>0.96</td>
<td></td>
<td>2.5</td>
<td>3.32</td>
<td>2.0</td>
<td>2.45</td>
<td>0.243</td>
<td>0.816</td>
<td>1.3</td>
<td>1.89</td>
<td>0.3</td>
<td>0.50</td>
</tr>
<tr>
<td>Grallina cyanoleuca</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>1.0</td>
<td>2.00</td>
<td>0.00</td>
<td></td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Species</td>
<td>3.0</td>
<td>2.94</td>
<td>1.0</td>
<td>2.00</td>
<td>1.124</td>
<td>0.304</td>
<td>6.5</td>
<td>3.79</td>
<td>1.0</td>
<td>2.00</td>
<td>2.57</td>
<td>0.042*</td>
<td>2.0</td>
<td>2.45</td>
<td>0.3</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>-------</td>
<td>-------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>------</td>
<td>--------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
</tr>
<tr>
<td>Gymnorhina tibicen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hirundo nigricans</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>6.3</td>
<td>2.63</td>
<td>0.0</td>
<td>0.0</td>
<td>6.3</td>
<td>4.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manorina melanocephala</td>
<td>4.8</td>
<td>1.89</td>
<td>2.5</td>
<td>2.082</td>
<td>1.599</td>
<td>0.161</td>
<td>16.0</td>
<td>6.78</td>
<td>1.5</td>
<td>2.38</td>
<td>4.035</td>
<td>0.007*</td>
<td>4.5</td>
<td>3.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Neochinia temporalis</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>5.5</td>
<td>11.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.0</td>
<td>4.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philemon corniculatus</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.8</td>
<td>7.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platycercus eximines</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>3.0</td>
<td>3.83</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>1.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhipidura leucophrys</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.0</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhipidura rufifrons</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>1.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhipidura fuliginosa</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2.3</td>
<td>0.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sturnis vulgaris</td>
<td>1.0</td>
<td>2.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

143
Abundance and diversity of competitive birds differed in similarity between the edge and cores over the three seasons. During spring the sites were most similar ($R = 0.063$, $P = 0.343$), however, edge sites were more similar (group average 64.3%) than core sites (53.6%; Figure 6.7).

No similarity in bird populations between edge and core sites were recorded for either autumn ($R = 0.865$, $P = 0.029$) or summer ($R = 0.552$, $P = 0.029$). In summer edge sites were more similar (group average 62.4%) than core sites (52.7%; Figure 6.7). However, during autumn within sites similarities were comparable; the group of sites sampled as edges averaged 42%, while the core group of sites averaged 46.2% (Figure 6.8).

Spearman’s rank correlation indicated that there were only weak relationships between the spring avian assemblage and skink distribution (Table 6.7). The strongest correlation recorded ($P = 0.332$) was recorded for a number of combinations of bird species.

The Spearman’s rank correlation for summer indicated that moderate associations existed between avian abundance and diversity, and skink presence throughout edge and core areas (Table 6.8). The strongest correlation recorded included between 3 and 5 species ($P = 0.640$). Among these was the noisy miner.

The autumn avian assemblage had the strongest correlations with skink distribution between core and edge areas of remnants (Table 6.9). Spearman’s rank correlation indicated that 11-12 species combined had the greatest impact on skink distribution
This group included the three introduced species; common myna *Acridotheres tristis*, cattle egret *A. ibis*, and common starling. Also among this group was the most commonly observed species in edge areas the noisy miner.

**Figure 6.7.** MDS plots (derived from Bray-Curtis similarity) based on competitor avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲), during spring. Edge sites displayed greatest similarity as a group (average 64.3%). Core sites were less similar than edge sites (average 53.6%). Sites were similar ($R = 0.063, P = 0.343$).
Figure 6.8. MDS plots (derived from Bray-Curtis similarity) based on competitor avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲), during summer. Edge sites displayed greatest similarity as a group (average 62.4%). Core sites were less similar than edge sites (average 52.7%). There is no similarity between edge and core sites ($R = 0.552, P = 0.029$).

Figure 6.9. MDS plots (derived from Bray-Curtis similarity) based on competitor avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲), during autumn. Core sites displayed greatest similarity as a group (average 46.2%). Edge sites were less similar than core sites (average 42%). Sites were not similar ($R = 0.865, P = 0.029$).
Table 6.7. Spearman’s rank correlation, conducted on various combinations of the 23 competitive avian species with skink numbers, during spring. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001.

<table>
<thead>
<tr>
<th></th>
<th>Dacelo novaehollandia</th>
<th>Cuculus canorus</th>
<th>Ciconia melanoleucoides</th>
<th>Ciconia novaehollandia</th>
<th>Anas ibis</th>
<th>Rhipidura fuliginosa</th>
<th>Rhipidura rufifrons</th>
<th>Phalacrocorax lucidus</th>
<th>Gymnorhina tibicen</th>
<th>Grallina cyanoleuca</th>
<th>Hirundo rustica</th>
<th>Manorina melanocephala</th>
<th>Maricaea branickii</th>
<th>Corvus corone</th>
<th>Corvus cornix</th>
<th>Cyanopica cyanus</th>
<th>Acaciphaga heinei</th>
<th>Cacatua roseicapilla</th>
<th>Platycercus eximius</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.332</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.332</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.332</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.332</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.332</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.332</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.332</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.307</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.307</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.251</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>0.227</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.152</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>0.030</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>-0.034</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>-0.115</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.8. Spearman’s rank correlation, conducted on various combinations of the 23 competitive avian species with skink numbers, during summer. The results reported are the combinations (donated by X) that best explain skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2002.

<table>
<thead>
<tr>
<th></th>
<th>Dacelo novaehollan</th>
<th>Cracticus torquatus</th>
<th>Corcorax melanocephalum</th>
<th>Coracina novaehollan</th>
<th>Ardea ibis</th>
<th>Rhipidura fuliginosa</th>
<th>Rhipidura rufifrons</th>
<th>Rhipidura leucophrys</th>
<th>Neochmia temporalis</th>
<th>Ptiliogonys ornatus</th>
<th>Gymnornis a tibicen</th>
<th>Grallina cyanoleuca</th>
<th>Hirundo neoxena</th>
<th>Acridotheres s tristis</th>
<th>Manorina melanocephala</th>
<th>Corvus coronoides</th>
<th>Sturnus vulgaris</th>
<th>Acathina pusillula</th>
<th>Pardalotus xanthodermus</th>
<th>Calyptorhynchus clanculoides</th>
<th>Calyptorhynchus galericulatus</th>
<th>Calyptorhynchus roseicapilla</th>
<th>Platycercus exigatus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.526</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.579</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.640</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.640</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.640</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.640</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.575</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.575</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.575</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.575</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.575</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.575</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.575</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.490</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.450</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.401</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>0.357</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0.355</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>0.312</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.278</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>0.165</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.080</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>-0.077</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6.9. Spearman’s rank correlation, conducted on various combinations of the 23 competitive avian species with skink numbers, during autumn. The results reported are the combinations (donated by X) that best explains skink distribution throughout the edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001.

|   | Dacelo novaehollandiae | Cacatua tenuis | Corvus macrorhynchos | Corvus novae-hollandiae | Ardea ibis | Rhynochetos flavipes | Rhipidura fuliginosa | Rhipidura rufifrons | Neochmia temporalis | Philemon corniculatus | Gymnorhina tibicen | Gallina gallina | Amadina nigriceps | Acanthiza pyuilla | Cormobates leucophrys | Calampis mystacalis | Cracticus torquatus | Corcorax melanocephalus | Acrocephalus roseicapillus | Platycercus eximius |
|---|------------------------|--------------|-----------------------|-------------------------|------------|----------------------|---------------------|---------------------|---------------------|----------------------|-------------------|----------------|---------------------|-----------------|--------------------------|-----------------|----------------|----------------|----------------|-------------------|----------------|----------------|
| 1 | 0.669                  |              |                       |                         |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 2 | 0.777                  | X            |                       |                         |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 3 | 0.797                  | X            | X                     |                         |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 4 | 0.782                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 5 | 0.823                  | X            | X                     |                         |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 6 | 0.823                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 7 | 0.835                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 8 | 0.853                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
| 9 | 0.895                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|10 | 0.901                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|11 | 0.903                  | X            | X                     |                         |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|12 | 0.903                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|13 | 0.890                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|14 | 0.883                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|15 | 0.878                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|16 | 0.877                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|17 | 0.841                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|18 | 0.824                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|19 | 0.805                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|20 | 0.781                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|21 | 0.756                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|22 | 0.732                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
|23 | 0.691                  | X            | X                     | X                       |            |                      |                     |                     |                     |                      |                   |                |                    |                 |                          |                 |              |              |              |                    |              |
6.4. Discussion.

Competitive bird numbers were greater in perimeter areas. Among the species encountered in these areas, the most abundant was the noisy miner. Diversity, however, was slightly greater in the interior areas compared to the perimeter. This is consistent with other studies. For example, Scott et al. (2006) indicated that of the 70 species of birds encountered in arid spiny forests, only 26% inhabited edge areas. When forested areas were compared with road verges, there was a difference in the diversity of non-passerine birds between the two (Arnold, 2003). These authors among others (e.g. Ford et al., 1988; Catterall et al. 1991) have indicated that the most likely cause of edge and core diversity differences is foraging behaviour. That is, terrestrial and aerial feeders are more likely to inhabit edge areas, whilst arboreal foragers are more likely to be interior specialists. For example, Catterall et al. (1991) and Scott et al. (2006) determined that arboreal insectivorous birds avoided edges in favour of the interior area in forests, due to fewer disturbances.

The birds encountered in this study varied in their foraging behaviour. Those that inhabited both the edge and core were able to forage in a variety of niches, such as on the ground or they could swoop from vantage points. However, of those that exclusively utilised the core (grey and rufous fantails, brown thornbill, white-throated treecreeper, red brow finch, noisy friarbird, tree martin and willie wagtail), only one (the willie wagtail) was able to forage on the ground (Ford et al., 1988), and one in the undergrowth (grey fantail). The majority of these ‘core specialist’, therefore, foraged in niches that would not bring them into competition with the most commonly encountered skinks *L. guichenoti* and *L. delicata*. However, *C. virgatus*,
(a primarily arboreal skink) forages on tree trunks (Greer & Jefferys, 2001), is more likely to share similar foraging niches to some of these birds. There may be a pattern of competition between birds and these skinks in core areas that could explain why this one species of skink maintains a slightly greater presence in edge areas as opposed to the core. However, it is more likely that core areas are not conducive to \textit{C. virgatus} in terms of habitat requirements.

The birds identified as inhabiting the edges predominately forage in niches that would bring them in direct contact with small skinks (e.g. white-winged choughs and the Australian raven), and they could have an impact on skink distribution.

Among the likely competitive birds were three introduced species; cattle egret, common myna and common starling. Much of the literature is peppered with reports of introduced species competing with native taxa. For example, the introduced American mink \textit{Mustela vison}, was able to exploit the resources in both terrestrial and aquatic environments within the Teign River system (Devon, England), at the expense of the endemic Eurasian otter \textit{Lutra lutra}, because native otters were more selective in their diet (Bonesi \textit{et al.}, 2004). Similarly the exotic grey squirrel \textit{Sciurus carolinesi} was a more aggressive hunter and able to claim better nesting sites than the native red squirrels \textit{S. vulgaris} throughout the United Kingdom (Gurnell \textit{et al.}, 2004).

Previous studies conducted on the three exotic bird species encountered in this study, have indicated that they have the potential to out-compete native species. For example, both the common myna and common starling are reported to be a threat to
endemic hollow-nesting birds, due to their aggression (Pell & Tidemann, 1997; Yap & Sodhi, 2004; Antos et al., 2006). Cattle egrets have been reported to dominate foraging grounds, primarily through intimidation generated by their flock size and noise (McKilligan, 1984; McKilligan, 2001).

The competitive impact these three taxa may have on small skinks has not been previously reported. Although the distribution of the three introduced birds encountered in this study had a negative correlation with skink distribution in the remnants (particularly in autumn), their impact was no more evident than any of the native avian species. The common myna was also more abundant in core areas, than in the edge and if this species was having a detrimental affect on skink distribution, it would be expected that skink numbers would reflect this.

The avian more commonly observed inhabiting the edges of the study sites displayed behaviour that was either aggressive (e.g. Australian magpie; Grey et al., 1998) and/or noisy (e.g. sulphur crested cockatoos; Heinsohn et al., 2003). This type of behaviour is designed to interfere with, or exclude competitive species from utilising the same foraging grounds. For example, aggressive behaviour displayed by the Australian magpie was successful in excluding white-winged choughs from grassland areas of forest remnants (Cox & Bauer, 1997), while the aggression of noisy miners has been linked to a reduction of smaller bird species in fragmented eucalypt forests (Piper & Catterall, 2003). Behavioural conflict between sulphur crested cockatoos and eclectus parrots Eclectus roratus, forced the latter to remain in their nests for longer periods to protect their territory (Heinsohn et al., 2003).
The aggressive nature of the birds encountered in edge areas of this study, could interfere with the normal behaviour of skinks, by preventing or reducing their foraging efforts. This behaviour has been noted in other competitive relationships. For example, the Nile monitor *Varanus niloticus*, interferes with the hunting techniques (by biting) of dwarf crocodiles *Osteolaemus tetraspis*, as they both compete for the same prey (Luiselli *et al.*, 1999). The aggression displayed by killer whales *Orcinus orca*, has been reported to force white sharks *Carcharodon carcharias*, out of their traditional foraging areas off the coast of Farallon Island (Pyle *et al.*, 1999). The larger more aggressive alpine skink *Niveoscincus greeni*, was able to retain the more profitable foraging and basking areas at the expense of more timid and smaller member of the genus, *N. microlepidotus* (Melville, 2005).

As an extension of aggressive and noisy behaviour, some of the birds encountered in this study employ a flocking behaviour and move into areas in relatively large groups, and exclude all but the most aggressive inhabitants. For example, cattle egrets moved into the edge area during the summer season when fields adjacent to the remnants were being prepared for planting. From these fields the egrets extended their foraging activity into the edge areas of the remnants that abutted the paddocks. During this time few other birds were seen actively foraging in the same areas. This behaviour has been observed in this species, both internationally (e.g. Kenya Wahungu *et al.*, 2003) and in Australia (McKilligan, 2001). Although many of the birds who employ flock foraging activities compete for resources over a more restricted time frame (i.e. they may remain from one day to a few weeks) or even seasonally, they have been known to dominate an area while present (Bomford & Sinclair, 2002; King, 2002; Temby & Marshall, 2003). Intimidating or interfering...
behaviour displayed by these birds may force skinks to alter their foraging behaviour and impact on the reptile’s health. This is because it is likely that the skinks may determine that the birds are a threat and employ ‘anti-predator’ behaviour in an attempt to avoid predation. Such behaviour may include hiding until the perceived threat has passed. For example, *L. guichenoti* has been known to remain hidden in refuge sites for most of its normal foraging time in the face of perceived threat. The result was that these skinks lost body condition and had smaller clutches (Downes, 2001).

Alternatively, skinks may elect to reduce their foraging territory so that they always remain close to refuge sites. For example, some small birds have demonstrated a reluctance to forage far from refuge sites, only venturing into less protected areas after exhausting food supplies close to refuges (Schneider, 1984). The lack of refuge sites for skinks has not been identified as an impediment to foraging in the habitat sampled. Anderson and Burgin (2002) assessed the habitat characteristics required by skinks in these edge areas, and found that habitat elements were equivalent in the core and edge of these remnants. Refuge sites, or lack thereof, are assumed not to be an impediment to skinks occupying edge areas.

The seasonal data indicated that there was a greater competitive effect between birds and skinks during autumn, than at any other time of the year. Although, both birds and skinks recorded lower abundance in edge areas during this time, there was a greater diversity of birds in the perimeter. This could be an artefact of bird migration patterns, which often influence the avian assemblage in an area during the cooler
months (Loyn, 2002). For example, the yellow-tailed black cockatoo was only observed in the remnants during autumn and they would be expected to utilise the area en route to the north where they remain during winter (Pizzey & Knight 1997). During this period encounter rates between birds and skinks may be increased as both prepare for the coming winter.

Autumn is a time when many skinks attempt to enhance their fat reserves before going into winter torpor (Brown, 1991; Pizzey & Knight, 1997). This allows them to survive the colder months and ensures that their body reserves are sufficient to allow for reproduction in spring (Wapstra & Swain, 1996). Birds also prepare for the cooler months when food is scarce (Loyn, 2002). In order to achieve these outcomes it would be expected that both birds and skinks would forage more intensely and as a result competition for resources between the two would be greater during that time.

While the anti-competitive behaviour employed by birds (i.e. aggression, noise or flocking) may not be directly aimed at small skinks, it is inevitable that such behaviours would be intimidating. This could cause skinks to abandon the perimeter in favour of the interior of the remnants.

Since many of the birds encountered more frequently in edge areas forage for arthropods and a range of small vertebrate prey, including skinks (Barker & Vestjens, 1984b, a; Marchant & Higgins, 1990), it is likely that small skinks would flee from them. This places these two groups in a possible exploitative competitor relationship. That is, birds are able to compete for resources with skinks, and at the same time prey upon them thus expanding their interaction from competitor to
predator. This type of interaction has been reported in other competition predator relationships. For example, the native kit fox *V. macrotis mutica*, competes for food and shelter with the introduced red fox *V. vulpes*. The red fox, the more aggressive and larger of the two, invaded the dens of the kit fox and preyed upon the cubs and weak older members of the species (Clark *et al.*, 2005).

This could explain why birds are found in edges in greater numbers while skinks are in the greater numbers in core of remnants. Adolf and Roughgarden (1986) speculated that skinks and birds are more likely to interact as predator and prey than as competitors. This would appear to be a more practical explanation to skink distribution than competition.

7.1. Introduction.

One of the major foci of ecologists over the years has been to identify the effects land clearance has on the interaction between various occupants of native ecosystems (Serio-Silva & Rico-Gray, 2002). Of particular concern is the effects reduced habitat has on the relationship between predators and prey (Cardinale et al., 2006).

This relationship has long been recognised as crucial to the way communities are structured, in so far as the number of predators and the proportion of prey they consume can determine the dynamics of the overall ecosystem (Miller et al., 2006). No animal can survive without food and, therefore, the availability of suitable prey may affect the distribution of predators throughout the landscape (Cooper & Vitt, 2002).

In modified habitats, such as edges, there have been reports of changes to the predator/prey dynamics (Gates, 1991; Saunders et al., 1991; Kilgo, 2005). Traditionally edges have been seen as problematic and were viewed as travelling lines (Kaiser, 1983; Vickery et al., 1992) that give generalist predators access to areas from which they would normally be excluded (Bider, 1968; Gates & Gysel, 1978; Janzen, 1986). This hypothesis has been extended so that edges are more generally described as funnels for predator movement, regardless of their dietary preference (Dyer et al., 2001). However, many believe that edges have prompted an
alteration of predator behaviour that allows them to utilise the interface more effectively. This could be correct in anthropogenically created environments. For example, there is evidence to suggest that some predators (e.g. foxes; Molsher et al., 2000; birds; Catterall et al., 1991) have become successful in cross foraging between the perimeter of remnants and their surrounding systems and it has been suggested that this ability has led to increase in their presence in edge areas (Berry, 2001). For example, Catterall et al. (1991) determined that edge areas were inhabited by a different suite of birds than was the core. These birds were typically larger and omnivorous. They were also able to expand their foraging grounds by including not only the perimeter of remnants, but also the surrounding areas. This allowed more such avian predators to inhabit the area, as they could subsidise their food intake with what was found in the less traditional habitats. These findings have been further demonstrated in other studies (e.g. Bentley & Catterall, 1997; Major et al., 2001; Shirley & Smith, 2005). However, there is a dearth of information on what effects such increases can have on the natural prey of birds. For example, avian are often a major predator of lizards (Greene, 1988). Despite this, little research has been conducted on the impacts an increase in bird predators may have on lizards occupying edge areas.

Current knowledge of reptile use of edges is scant (exceptions include Brown & Nelson, 1993; Conroy, 1999). Absent is information pertaining to small reptiles, although they are key species in native ecosystems (Brown & Nelson, 1993). Much of the information available concerns their response to logging (Lunney et al., 1991; Webb, 1995; Goldingay et al., 1996), fire (Lunney et al., 1991; Taylor & Fox, 2001),
mine rehabilitation (Twigg & Fox, 1991; Taylor & Fox, 2001), and grazing (Abensperg-Traun et al., 1996; Smith et al., 1996) disturbances.

The work that has been conducted indicates that small (SVL ≤ 55 cm) generalist skinks, in Western Sydney, NSW, responded poorly to edge habitats and maintained more viable populations in central remnant areas (Anderson & Burgin 2002). The cause of this effect was not determined. However, it was suggested that increased avian predators in edge areas could be responsible. To investigate this, the following questions are investigated in this chapter:

- Is there an increase in predatory avian in edge areas?
- If so, does this increase the attack rate on small skinks within the perimeter area?
- What is the success rate of avian attacks on these skinks (i.e. whether skinks have a chance to escape an attack or not)?
- Finally, do avian predators target a particular size of these skinks?


Selection of sites is presented in Chapter 2.
7.2.1. Animal Sampling

Skink (Chapter 3.2.1) and avian (Chapter 3.2.2) data were collected as described previously.

Birds recorded were categorised as predators based on information gleaned from the literature (Barker & Vestjens, 1984b, a; Higgins & Davies, 1996; Higgins, 1999; Higgins et al., 2001), and observations made during the study.

7.2.3. Predation rates

Predation rates on skinks were tested to determine if there was an increase in attacks at the edge compared to the core of remnants.

Predator attack rates were measured using artificially created skinks, or decoys. Decoys were constructed of either plastic or latex and cast in a basking position (c.f. Schneider, 1984; Olsson, 1993). Their proportions were based upon the three life stages (adult, sub-adult and juvenile; Joss & Minard, 1985) of the most abundant skink in the study area (L. guichenoti, Anderson & Burgin, 2002). Each ‘animal’ was threaded with 15lb fishing line; this allowed them to be tethered via a galvanised nail to the substrate. They were overlayed with 3-M’s Blu-tac™ and painted either ‘metallic grey’ or ‘metallic brown’ with Folk Art paint (Plate 7.1).

Decoys were placed throughout the edge and core of remnants, along a randomly selected transect, the length of which varied according to the availability of appropriate tethering points. On each transect 15 decoys (5 of each size) were placed
on logs, fallen branches and/or tree stumps, to mimic skink basking behaviour. The decoys were left in position for seven days. After that time they were collected and examined for unambiguous beak mark impressions (Plate 7.2). The size of the decoy (juvenile, sub-adult or adult) and the position on the body of the decoy (head, torso or tail, Figure 7.1) where marks were made by predators were recorded. If multiple marks were observed only one attack was counted, unless one of the marks included the tail. As a tail attack usually demonstrates a ‘miss’ by the predator, it was deemed that the skink could have lived and been attacked on another occasion. The procedure was repeated on new transects at the end of the week.

Data were collected in each season between summer 2000 and autumn 2002. The aim was to collect information over a four-week period in each season, except in spring when data was collected for eight weeks. At the end of each four week period, sites were rested for a minimum of two weeks, to ensure birds did not become familiar with the decoys and avoid them.

The sampling periods had to be modified in some seasons due to circumstances beyond the control of the researcher. Sampling in summer 2002 was commenced in December 2001, but was interrupted by bush fires and heavy rains. Sampling could not recommence until the end of February 2002. This delayed the commencement of the autumn 2002 sampling. Due to decreasing temperatures (which reduce skink activity) the sampling ceased after two weeks. Autumn 2002 data were, therefore, excluded from seasonal predation analysis. Also the last four weeks data collected during spring 2001 was also excluded from this analysis.
Plate 7.1. Decoys shown represent juvenile (top), sub-adult (centre) and adult (bottom), model (bottom), covered in blu-tac (middle) and painted (top).

Plate 7.2. Adult decoy after avian attack. The red circles highlight two distinctive beak marks. The one closest to the head represents an attack from above, while the mark on the lower torso region represents a side-on attack.
7.2.4. Analyses of predation data.

Data were organised and analysed by number of attacks, decoy size and location of attack, both overall and seasonally. These analyses were undertaken using ANOVA (one, two and three way, as appropriate). Tukey’s HSD (pairwise) test was utilised as a post hoc analysis of significant data.

Other procedures used in the analysis are presented in Chapters 3.2.4 and 5.2.4.
7.3 Results.

7.3.1. Skink Abundance and Diversity

Skink abundance and diversity results are presented in Chapter 3.3.2.

7.3.1. Avian Predator Abundance and Diversity.

A total of 445 predatory birds, from seven species (Cr. torquatus, Corcorax melanorhamphos, D. novaeguinae, G. tibicen, M. melanocephala, Corvus coronoides and Sturnus vulgaris), 311 in edge areas and 134 in core areas, were encountered (Figure 7.1 and 7.2).

Rank abundance demonstrated that avian presence followed the trend lines (Figure 7.3). The ranking of the species did not differ overtly, except for magpies G. tibicen, which were the most abundant on the edge, but only the 6th most abundant in the core. However of the seven predatory species encountered, only two demonstrated any significant difference between core and edge; the grey butcherbird Cr. torquatus, and the noisy miner M. melanocephala. Both species were more common on the edge sites than in the core of remnants (Table 7.1).

There was no similarity in predator bird populations between edge and core sites ($R = 0.427, P = 0.029$). Edge sites were more similar (group average 84.2%) than core sites (72.7%; Figure 7.4).
Figure 7.1. The abundance of identified predatory bird species encountered across edge (■) and core (■) sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

Figure 7.2. Mean number (SD and SE) of predatory birds encountered across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.
**Figure 7.3.** Rank abundance curves (and corresponding orders) in edge (■) and core (▲) of woodland remnants in peri-urban north-western Sydney, 2001/02, for predatory avian. Plotted lines are linear trend-lines (edge, $R^2 = 0.85$; core, $R^2 = 0.99$)
Figure 7.4. MDS plots (derived from Bray-Curtis similarity) based on predator avian abundance and diversity, collected from the 4 edge (■) and 4 core sites (▲). Edge sites displayed greatest similarity as a group (average 84.2%). Core sites were less similar than edge sites (average 72.7%). There is no similarity between edge and core sites ($R = 0.427, P < 0.029$).

Table 7.1. Mean number, standard deviation and t-test (* donates significance at 0.05) of the predatory avian species, encountered across all edge and core sites of woodland remnants in peri-urban northwestern Sydney, 2001/02.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common Name</th>
<th>Edge Mean</th>
<th>Edge S.D.</th>
<th>Core Mean</th>
<th>Core S.D.</th>
<th>T value (d.f. 6)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Corcorax melanocephala</em></td>
<td>White-winged chough</td>
<td>14.0</td>
<td>15.10</td>
<td>14.3</td>
<td>6.40</td>
<td>0.030</td>
<td>0.977</td>
</tr>
<tr>
<td><em>Corvus coronoides</em></td>
<td>Australian raven</td>
<td>14.5</td>
<td>11.09</td>
<td>7.5</td>
<td>1.91</td>
<td>1.244</td>
<td>0.260</td>
</tr>
<tr>
<td><em>Cracticus torquates</em></td>
<td>Grey butcherbird</td>
<td>8.5</td>
<td>3.70</td>
<td>4.0</td>
<td>0.96</td>
<td>3.797</td>
<td>0.009*</td>
</tr>
<tr>
<td><em>Gymnorhina tibcen</em></td>
<td>Australian magpie</td>
<td>10.8</td>
<td>8.18</td>
<td>2.3</td>
<td>2.63</td>
<td>1.978</td>
<td>0.095</td>
</tr>
<tr>
<td><em>Manorina melanocephala</em></td>
<td>Noisy miner</td>
<td>25.3</td>
<td>7.37</td>
<td>5.3</td>
<td>6.65</td>
<td>4.030</td>
<td>0.006*</td>
</tr>
<tr>
<td><em>Sturnus vulgaris</em></td>
<td>Common starling</td>
<td>1.0</td>
<td>2.00</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Dacelo novaeguineae</em></td>
<td>Laughing kookaburra</td>
<td>4.3</td>
<td>5.32</td>
<td>3.0</td>
<td>3.06</td>
<td>0.404</td>
<td>0.700</td>
</tr>
</tbody>
</table>

7.3.2. Predator/Prey Interaction

Spearman analyses indicated that no one species of bird explained the distribution of skinks throughout the core or edge. However, all of the correlation patterns recorded
moderate to strong relationships between bird and skink distribution. The best result was with a combination of 5 species \( (P = 0.894; \text{Table 7.2}).

**Table 7.2.** Spearman’s rank correlation, conducted on various combination of the 7 predator avian species with skink numbers. The results reported are the combinations (donated by X) that best explain skink distribution throughout edge and core areas of woodland remnants in peri-urban north-western Sydney, 2001/02.

<table>
<thead>
<tr>
<th>P Value</th>
<th>Cracticus torquatus</th>
<th>Corvus melanorhamphos</th>
<th>Manorina melanocephala</th>
<th>Gymnorhina tibetana</th>
<th>Corvus coronoides</th>
<th>Dacelo novaeguineae</th>
<th>Sturnus vulgaris</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.589</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.723</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.791</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.870</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.894</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.866</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>0.766</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**7.3.3. Predation Rates.**

**7.3.3.1. Spatial.**

A total of 2160 decoys were used over the full sample period, 827 were unambiguously attacked by birds; 475 attacked on the edge and 352 on the core (Figure 7.5). The rate of the attacks was significantly different between the edge and the core \( (P > 0.035, \text{df 1}).\)
The analysis indicated little variation on attacks over the three strike zones (Figure 7.6). Strikes on the tail that represented a likely miss for the predator translated to 28% on the edge and 29% on the core. There was no significant difference between location ($P > 0.201$), anatomical zone ($P > 0.584$) or the interaction ($P > 0.955$).

Amongst the size classes, a total of 37% adults, 32% sub-adults and 31% juvenile decoys were attacked over the sample period. Overall more were attacked on the edge (adults – 58%; sub-adults – 59%; juveniles – 57%) compared to the core (adults – 42%; sub-adults – 41%; juveniles – 43%; Figure 7.7). There was a significant difference between the edge and the core, but not between the size groupings and therefore, not with or between the interaction (Table 7.3).

Anatomical location of attacks over the three sized decoys (Figure 7.8) was significantly different between the edge and the core (Table 7.4).
Figure 7.5. Mean number (SD and SE) of attacks by birds on decoys across all edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, 2001/02.
Figure 7.6. Mean number (SD and SE) of attacks based on anatomical location of attack on decoys, across all edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, 2001/02.

Table 7.3. Two-way ANOVA results for avian attacks across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02 (** donates significance at 0.01, NS donates not significant).

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>F Value</th>
<th>Df</th>
<th>P Value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (edge/core)</td>
<td>16.545</td>
<td>1</td>
<td>0.0007</td>
<td>**</td>
</tr>
<tr>
<td>Size</td>
<td>1.179</td>
<td>2</td>
<td>0.330</td>
<td>NS</td>
</tr>
<tr>
<td>Location X Size</td>
<td>0.002</td>
<td>2</td>
<td>0.998</td>
<td>NS</td>
</tr>
</tbody>
</table>
Figure 7.7. Mean number (SD and SE) of attacks on decoys both temporally and spatially across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.
Figure 7.8. Mean number (SD and SE) of attacks, location of attack on the decoys and size of decoy, temporally across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.

Table 7.4. Three-way ANOVA results table for avian attacks based on the size of the decoy, across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02 (*** donates significance at 0.001; NS donates not significant).

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>F Value</th>
<th>Df</th>
<th>P Value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (edge/core)</td>
<td>14.04</td>
<td>1</td>
<td>0.0004</td>
<td>***</td>
</tr>
<tr>
<td>Size</td>
<td>0.59</td>
<td>2</td>
<td>0.556</td>
<td>NS</td>
</tr>
<tr>
<td>Attack zone</td>
<td>1.08</td>
<td>2</td>
<td>0.348</td>
<td>NS</td>
</tr>
<tr>
<td>Location X Size</td>
<td>1.79</td>
<td>2</td>
<td>0.837</td>
<td>NS</td>
</tr>
<tr>
<td>Location X Attack zone</td>
<td>0.41</td>
<td>2</td>
<td>0.669</td>
<td>NS</td>
</tr>
<tr>
<td>Size X Attack zone</td>
<td>0.29</td>
<td>4</td>
<td>0.881</td>
<td>NS</td>
</tr>
<tr>
<td>Location X Size X Attack zone</td>
<td>0.22</td>
<td>4</td>
<td>0.928</td>
<td>NS</td>
</tr>
</tbody>
</table>
7.3.3.2. Spatial and Temporal Attacks

The seasonal data were based on a total of 1920 decoys with 668 attacked; 388 on the edge and 280 in the core (Figure 7.9). A significant difference was observed between core and edge, but no significance difference was found among seasons or at the interaction level (Table 7.5). However the p value of 0.0514, obtained for between seasons, was only marginally outside the probability value of 0.05. Tuckey’s HSD test indicated a significant relationship between the two summer seasons (P > 0.001).

Attacks based on size of decoys yielded 38% adults, 31% sub-adults and 31% juvenile decoys attacked. Attacks occurred in a higher number on the edge (adults – 56%; sub-adults – 59%; juveniles – 60%) than the core (adults – 44%; sub-adults – 41%; juveniles – 40%; Figure 7.10). A significant difference was observed between the edge and core, season, size and the interaction between season and size (Table 7.6). No significant difference was discernable with other interaction levels. Tukey’s HSD demonstrated a significant relationship between the two summer seasons (P > 0.0002) and between adult and juvenile size (P > 0.038). A significant relationship was also observed in the season x size interaction (Table 7.7).
Figure 7.9. Mean number (SD and SE) of attacks on decoys, both temporally and spatially, across all edge and core sites sampled in woodland remnants in peri-urban north-western Sydney, 2001/02.

Table 7.5. Two-way ANOVA results table for avian attacks on decoys, spatial and temporally, across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02 (* donates significance at 0.05. NS donates not significant).

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>F Value</th>
<th>Df</th>
<th>P Value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (edge/core)</td>
<td>8.85</td>
<td>1</td>
<td>0.004</td>
<td>*</td>
</tr>
<tr>
<td>Season</td>
<td>2.66</td>
<td>3</td>
<td>0.514</td>
<td>NS</td>
</tr>
<tr>
<td>Location X Season</td>
<td>0.67</td>
<td>3</td>
<td>0.574</td>
<td>NS</td>
</tr>
</tbody>
</table>
Table 7.6 Three-way ANOVA results table for avian attacks on size structure, spatial and temporally, across all edge and core sites woodland remnants in peri-urban north-western Sydney, 2001/02 (* donates significant at 0.05; *** donates significant at 0.001; NS donates not significant).

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>F Value</th>
<th>Df</th>
<th>P Value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (edge/core)</td>
<td>18.96</td>
<td>1</td>
<td>0.00002</td>
<td>***</td>
</tr>
<tr>
<td>Season</td>
<td>5.68</td>
<td>3</td>
<td>0.0001</td>
<td>***</td>
</tr>
<tr>
<td>Size</td>
<td>3.59</td>
<td>2</td>
<td>0.027</td>
<td>*</td>
</tr>
<tr>
<td>Location X Season</td>
<td>1.35</td>
<td>3</td>
<td>0.258</td>
<td>NS</td>
</tr>
<tr>
<td>Location X Size</td>
<td>0.15</td>
<td>2</td>
<td>0.867</td>
<td>NS</td>
</tr>
<tr>
<td>Season X Size</td>
<td>2.82</td>
<td>6</td>
<td>0.011</td>
<td>*</td>
</tr>
<tr>
<td>Location X Season X Size</td>
<td>0.31</td>
<td>6</td>
<td>0.931</td>
<td>NS</td>
</tr>
</tbody>
</table>

Figure 7.10. Mean number (SD and SE) of attacks based on the size of the decoy, both temporally and spatially, across all edge and core sites of woodland remnants in peri-urban north-western Sydney, 2001/02.
Table 7.7. Tukey’s HSD applied to both spatial and temporal attacks based on the size of the decoy across all edge and core sites of woodland remnants in peri-urban northwestern Sydney (* donates significant at 0.05; ** donates significant at 0.01; *** donates significant at 0.001; NS donates not significant).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 1 – Adult</td>
<td></td>
<td>0.0006***</td>
<td>0.1148</td>
<td>0.9984</td>
<td>0.8549</td>
<td>0.8549</td>
<td>0.9849</td>
<td>0.9731</td>
<td>0.8549</td>
<td>1.0000</td>
<td>0.9998</td>
<td>0.9994</td>
</tr>
<tr>
<td>Summer 1 – Sub-adult</td>
<td>0.0006***</td>
<td></td>
<td>0.9554</td>
<td>0.0271*</td>
<td>0.2309</td>
<td>0.2309</td>
<td>0.0670</td>
<td>0.0883</td>
<td>0.2309</td>
<td>0.0014**</td>
<td>0.00003***</td>
<td>0.0195*</td>
</tr>
<tr>
<td>Summer 1 – Juvenile</td>
<td>0.1148</td>
<td>0.9554</td>
<td></td>
<td>0.6814</td>
<td>0.9849</td>
<td>0.9849</td>
<td>0.8549</td>
<td>0.8970</td>
<td>0.9849</td>
<td>0.1856</td>
<td>0.0098**</td>
<td>0.6128</td>
</tr>
<tr>
<td>Autumn – Adult</td>
<td>0.9984</td>
<td>0.0271*</td>
<td>0.6814</td>
<td></td>
<td>0.9998</td>
<td>0.9998</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.9998</td>
<td>0.9998</td>
<td>0.8549</td>
<td>1.0000</td>
</tr>
<tr>
<td>Autumn – Sub-adult</td>
<td>0.8549</td>
<td>0.2309</td>
<td>0.9849</td>
<td>0.9998</td>
<td></td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.9304</td>
<td>0.3409</td>
<td>0.9994</td>
</tr>
<tr>
<td>Autumn – Juvenile</td>
<td>0.8549</td>
<td>0.2309</td>
<td>0.9849</td>
<td>0.9998</td>
<td>1.0000</td>
<td></td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.9304</td>
<td>0.3409</td>
<td>0.9994</td>
</tr>
<tr>
<td>Spring – Adult</td>
<td>0.9849</td>
<td>0.0670</td>
<td>0.8549</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td></td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.9693</td>
<td>0.6814</td>
<td>1.0000</td>
</tr>
<tr>
<td>Spring – Sub-adult</td>
<td>0.9731</td>
<td>0.0883</td>
<td>0.8970</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td></td>
<td>1.0000</td>
<td></td>
<td>0.9922</td>
<td>0.6128</td>
<td>1.0000</td>
</tr>
<tr>
<td>Spring – Juvenile</td>
<td>0.8549</td>
<td>0.2309</td>
<td>0.9849</td>
<td>0.9998</td>
<td>1.0000</td>
<td>1.0000</td>
<td></td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.9304</td>
<td>0.3409</td>
<td>0.9994</td>
</tr>
<tr>
<td>Summer 2 – Adult</td>
<td>1.0000</td>
<td>0.0014**</td>
<td>0.1856</td>
<td>0.9998</td>
<td>0.9304</td>
<td>0.9304</td>
<td></td>
<td>0.9963</td>
<td>0.9922</td>
<td>0.9304</td>
<td></td>
<td>0.9984</td>
</tr>
<tr>
<td>Summer 2 – Sub-adult</td>
<td>0.9998</td>
<td>0.00003***</td>
<td>0.0098**</td>
<td>0.8549</td>
<td>0.3409</td>
<td>0.3409</td>
<td>0.6814</td>
<td>0.6128</td>
<td>0.3409</td>
<td>0.9984</td>
<td></td>
<td>0.8970</td>
</tr>
<tr>
<td>Summer 2 – Juvenile</td>
<td>0.9994</td>
<td>0.0195*</td>
<td>0.6128</td>
<td>1.0000</td>
<td>0.9994</td>
<td>0.9994</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.9994</td>
<td>0.9999</td>
<td>0.8970</td>
<td></td>
</tr>
</tbody>
</table>
7.3.4. Attack Correlations

Based on the number of attacks, regression analysis indicated predators significantly impacted on prey numbers over all remnants ($R^2 = 0.808; p < 0.007$). The number of attacks was moderately, although, negatively correlated with the abundance of prey ($r = -0.553$; Figure 7.11). A strong negative correlation also existed between predator and prey numbers ($r = -0.74$). The number of attacks was strongly correlated ($r = 0.876$) with the number of predators.

Figure 7.11. Correlations between skink (prey) numbers and the number of attacks on decoys ($r = -0.553$); avian (predator) numbers with skink numbers ($r = -0.741$); avian numbers with the number of attacks on decoys ($r = 0.808$).
7.4. Discussion.

7.4.1. Avian Abundance and Diversity.

The abundance and diversity of avian predators showed little similarity between the core and the edge with predators in greater numbers in perimeter areas. Edge areas were dominated by noisy miners, while interior areas were inhabited primarily by white-winged choughs, although greater numbers of this species was observed in edge areas.

Although noisy miners were encountered in greater numbers in edge areas, it has been suggested that they are primarily a honey eating bird, that take arthropods and small reptiles only to supplement their diet (Grey et al., 1998). These birds are therefore unlikely to take large numbers of skinks in comparison to the other predatory birds in this area. However, more recent studies have indicated that these birds eat prey more frequently than previously thought (O'Leary & Jones, 2006; Parsons et al., 2006). For example, Parsons, et al. (2006) indicated that noisy miners were more abundant in suburban gardens of Sydney, where meat was more readily available, than either seed or nectar. It could, therefore, be concluded that these birds are more carnivorous than previously assumed and may as predators, have a negative impact on skinks.

Noisy miners have been noted for their hyperaggressive behaviour, which they use to force competition out of their foraging grounds (Piper & Catterall, 2003). This behaviour usually results in their foraging sites being shared with other birds that can
match their aggression, for example, the Australian magpie and white-winged choughs (Cox & Bauer, 1997).

These species are ground foragers and are possibly of greater threat to skink populations, than the swoop and snatch foragers, such as the laughing kookaburra (Cox & Bauer, 1997). Both species have been identified as excluding the other from foraging areas. White-winged choughs are considered to be edge and interior foragers, while magpies inhabit grassland areas (Cox & Bauer, 1997). In this study, the behavioural patterns observed, support the previous evidence that magpies maintain a presence in both edge and core areas, when white-winged choughs were absent.

The increased presence of avian predators in edge habitats may be linked to their preference for utilising human-designed structures. Some predators, such as birds, utilise anthropogenic structures that offer a vantage point from which to launch attacks on prey in edge habitats (Wegner & Merriam, 1979). For example, Wegner and Merriam (1979) established that birds (in Canada) perched on fencerows using them as a look out from and to use as a spring board into foraging areas at the edge of remnants. Parsons et al. (2006) observed similar behaviour in noisy miners as they protected their territory from interlopers. This behaviour was noted during this study. Birds, such as laughing kookaburras and Australian magpies, observed both edge and grasslands from atop of powerlines and fences, either in or adjacent to the study sites. These perches offered a further advantage by allowing territorial birds to launch attacks on intruders.
Remnant size has been reported to influence avian species richness between perimeter and interior areas (Howe et al., 1981; Howe, 1984; Hagan et al., 1996; Namba et al., 1999). Larger remnants are more likely to show distinctive species changes between core and edge, while smaller remnants have been shown not to reflect this distinction (Campi & Mac Nally, 2001). The remnants utilised in this study are considered to be small (20 to 88 ha) and old (more than 100 years), and bird predatory species composition was consistent between the edge and the core, but numbers did alter significantly, with more birds in edge areas compared to core.

Habitat alteration in edge areas also could be a contributing factor to increased avian predator numbers (Mac Nally et al., 2000). Berry (2001) indicated that edge areas attracted open country birds more able to forage in the reduced vegetation coverage of edge areas. The birds most likely to utilise edges are those that can forage successfully in both edge and adjacent areas (McCollin, 1998). As indicated previously, avian most successful in edges tend to be large or aggressive species (Catterall et al., 1991; Antos et al., 2006). The predatory species encountered in edge areas during this study could be described in this way.

Ultimately, the attraction of predators to an environment is more likely to be prey related than for other reasons (Winter et al., 2000; Agosta et al., 2003). In terms of adequate foraging opportunity, foraging sites and potential success in finding food, it is likely that birds in this study were attracted to the edge.
7.4.2. Predator/Prey Interaction.

The distribution of avian predators throughout the remnant appeared to have an adverse effect on skink numbers. This indicates that the increased numbers of predators in edge areas is directly proportional to the decrease in skink numbers.

Escalating predator presence in an area does not always equate to reductions in prey numbers by increasing the mortality rate. Prey may alter their behaviour and habitat usage (Lima & Dill, 1990). For example, Caldwell (1986) observed that herons changed their foraging patterns when hawk numbers were higher. Tadpoles also adjusted their feeding patterns in the presence of increased predation threat and this behaviour resulted in a reduction in growth rates (Van Buskirk & Yurewicz, 1998). Altered growth rates were also reported in aphids and linked to the disturbance created by increased predator movement (Nelson et al., 2004). Dolphins forage closer to fishing vessels when large groups of sharks occupy their more traditional foraging grounds (Heithaus, 2001). Pied cormorants *Phalacrocorax varius*, also respond to the threat of sharks. They abandon areas with good supplies of food, close to the waters edge, when large groups of tiger sharks *Galeocerdo cuvier*, gathered (Heithaus, 2005). Due to increase predation by humans, the black *Milvus migrans*, and red kites *M. milvus*, abandoned park areas although they were rich with appropriate prey species (Sergio et al., 2005).

Conversely, increased predation risk can also equate to increase food consumption by prey. For example, stonefly nymphs *Agentina capitata* exposed to increased numbers of their major predator, the rainbow trout *Oncorhynchus mykiss*, had higher
stress levels. This caused them to consume a greater portion of their body weight, making them even more vulnerable to attack (Feltmate & Williams, 1991; Duvall & Williams, 1995). The bay scallop *Arogopecten irradians*, encountered in edges of seagrass beds, also increased their food intact in the face of increased predation risk, which subsequently increased their growth rates (Bologna & Heck, 1999).

The predation risk exerted on the skinks of this study may have affected their foraging behaviour. Skinks may have abandoned the edge in an attempt to minimise predation risk. An alternative explanation is that when these heliothermic lizards are confronted with increased predator pressure they will alter their use of substrate microhabitats (Greene, 1988; 1990; Cooper *et al*., 1990; Towns *et al*., 2003). They may also reduce their basking rate, which is required to maximise performance, and thereby reduce their opportunity to forage (Pough, 1980; Andrews, 1982; Huey, 1982), ultimately, trading off food and normal growth rates in exchange for safety (Downes, 2001).

This anti-predator behaviour has been observed in *L. guichenoti* when tested against an increased snake presence. In this situation the skinks remained sheltered for most of the day in what appeared to be an attempt to avoid detection. They consequently, reduced their mobility and foraging opportunities. As predicted, the result was a reduction in growth rates, leading to smaller mature body size and lighter clutch masses (Downes, 2001). Since the other commonly encountered species *L. delicata* forages in the same manner, is closely related and utilises the same nesting sites as *L. guichenoti*, it would be expected that they would respond similarly to increase predation risks.
Such a defence mechanism is not sustainable in times of persistent presence of predators. Survival ultimately requires access to resources such as food, mates and nesting areas, which can not be obtained if the skinks hide and abstain from foraging. This type of anti-predator behaviour may well have been in response to the prolonged use of the stimuli of snake scent. Downes (2001) applied scent once a week for four weeks and noted that as the scent dissipated, skinks foraged more frequently. As the snake odour was persistent, and skinks are more likely to detect the presence of avian predators via audio or visual cues, it is more likely that they would employ an alternative anti-predator behaviour than that observed with snakes. As Greene (1988) observed, skinks are more likely to employ a ‘run and hide’ response, re-emerging after the perceived threat has passed.

Fleeing predators, a basic anti-predation mechanism, requires that prey seek refuge in areas where they are less susceptible to attack (Holt, 1987; Taylor, 1988; Kramer & Bonenfant, 1997; Diego-Rasilla, 2003). In an edge prey have fewer safe directions to flee. That is, a skink basking near the edge of woodlands and confronted with danger may only move away from the edge back towards the safety of the remnant. A skink that elects to flee via the adjacent ecosystem, such as grassland, may expose themselves to the predator more readily than those able to flee into the remnant. For example, studies on the house mouse *M. musculus domesticus* in central western NSW, determined that when mice chose to flee a predator via grassy areas, they were more likely to be spotted and captured by their foe, than those who were able to escape to fallen trees (Arthur *et al.*, 2005). In the presence of an increased number of predators, skinks may well abandon the edge in preference for greater manoeuvring opportunities in the core.
Edges also often have fewer available refuges than intact habitat or there may be an increase in the distance between prey and suitable safe habitat. As distance from refuge increases, prey must respond earlier, resulting in a greater exertion of energy and lost time for other activities (Kramer & Bonenfant 1997). For example, Diego-Rasilla (2003) demonstrated that in areas of northern Spain, the *P. muralis* lizard’s flight initiation distance increased (i.e. the distance lizards allowed a predator to approach before fleeing) due to greater predator presence.

When prey are forced to abandon foraging areas close to refuges they maybe forced to utilise alternative anti-predator behaviour. For example, when the sand fiddler crabs *Uca pugilator*, who needed to move away from refuge areas in order to forage, they were observed to form tight groups when approached by a predator, sacrificing those on the outer edge, while protecting those in the centre. Downes (2001) reported a similar behaviour in her study of *L. guichenoti* and in their response to snake scent.

Lack of suitable refuge sites can also impact on choice of foraging areas for prey (Lima & Dill 1990). For example, some small birds have demonstrated a reluctance to forage far from refuge sites, only venturing into less protected areas after exhausting food supplies close to refuges (Schneider 1984). Likewise, the Suter’s skink *O. suteri*, found on the North Island of New Zealand, chose not to forage on beaches where there were no boulders and where Pacific rats (*R. exulans*) were present (Towns *et al.*, 2003).
There may well be other impediments in refuge selection in edge areas. For example, coppertail skinks *C. taeniolatus*, chose not to shelter under rock outcrops if ants and centipedes were present. It was suggested that these arthropods were determined to be predators, rather than prey, and that their presence reduced the number of suitable refuge sites for the skinks (Goldsbrough *et al.*, 2000). Given that ants were the most abundant arthropod found on the edge in this study (refer Chapter 3.3.1), it is possible that they could dominate some skink refuge sites, and perhaps deter skinks from the area.

The lack of refuge sites has not been identified as an impediment to foraging in the habitat sampled. Anderson and Burgin (2002) assessed the habitat characteristics required by skinks in these edge areas, and found that habitat elements were equivalent in the core and edge of these remnants.

The lower skink abundance in edge areas, compared to the core of remnants, in relation to higher avian predator presence, could be due to increase mortality rates in conjunction with avoidance behaviour.

Additionally, there is evidence that increased exposure to dangerous situations (such as increased risk of predation, can evoke high levels of stress in animals, which in turn can be detrimental to their overall health and well being (Koolhaas *et al.*, 1999). For example, the constant threat to sheep by wild dogs in Scotland resulted in the sheep suffering from chronic stress. This in turn resulted in increase parasitism, reduced wool growth and loss of body weight and lower sheep body condition (Dwyer & Bornett, 2004). Chronic stress levels in teleost fish have also been
recorded in areas of increased predator presence. The result was that fish feeding and socialising times were suppressed and this resulted in reduced body condition and made them more prone to disease and parasites (Hart, 1997). Increased vulnerability to parasite infection, due to stress created by increased threat of predation, was also recorded in the common lizard *Lacerta vivipara*, of southern France (Opplinger *et al.*, 1998).

The risk of parasitic infection in the skinks encountered in this study is relatively unknown. Only one reported a fatal mite infection in *L. delicata* has been recorded and the circumstances surrounding the infection were unknown (Domrow, 1981). Parasitic mites have been reported to infest Australian lizards (e.g. Smallridge & Bull, 2001; Walter & Shaw, 2002). However, the relationship between infestation and stress in small skinks remains relatively unexplored.

What is apparent from the literature is that stress, and particularly stress related to increased predation risk, can have a detrimental affect on an animal’s survival, directly or indirectly. Unverified stress could contribute to the decreased presence of skinks in edge areas.

**7.4.3. Predation Rates.**

Birds prey on small skinks in greater numbers in the perimeter of woodland remnants than in the interior. This predation pressure was sustained throughout the year.
Predators actively search for prey they know to be easy to catch, handle, and are palatable (Wourms & Wasserman, 1985). Continued persistence of predators in an area is dependent on availability and variety of prey (Robinson & Holmes, 1982; Ferguson, 2004b). For example, the predatory blue crab *C. sapidus* was present in lower numbers in areas where their natural prey, periwinkle snails *Littoraria irrorata*, were also in low abundance (Lewis & Eby, 2002). Likewise *B. regalaris* tadpole density has been correlated with the density of its prey, the larvae of African catfish *Heterobranchus logifillis* (Nguenga et al., 2000).

Most predators only take prey in proportion to their abundance (Bagchi & Sankar, 2003). Once a suitable prey item has been depleted, predators will either vacate the area or alternatively switch to a new prey item (Norrdahl & Korpimaki, 2000). In edge habitats the most successful predators cross-forage between the edge and into adjacent ecosystem/s. Predators using this tactic manage to reduce prey population sizes at the interface and maintain them at low levels (Andrén & Angelstam, 1988; Norrdahl & Korpimaki, 2000).

The avian predators in this study appear to be affecting skink abundance in this way. Through cross foraging, they are able to reach satiation levels, and preserve skink numbers at lower levels. Indeed the avian predators observed in the study’s edge areas are known for their adaptation to foraging in both natural and disturbed habitats (e.g. noisy miners, magpies), and most do not prey exclusively on skinks (e.g. kookaburras). Most consume skinks as a part of a omnivorous diet, which includes many of the arthropod species that are also consumed by small skinks (see Barker &
Vestjens, 1984b, a). This could improve encounter rates in edge areas as increased numbers of birds forage in the same areas as the skinks.

Edge areas often act as ecological traps, attracting animals by offering suitable habitat in which to disperse, while increasing their vulnerability to attack by predators (Pulliam, 1988; Namba et al., 1999; Kristan, 2003). The occurrence of a source/sink situation can occur in these types of environments. That is, the source area allows individuals to reproduce in excess of the mortality rate, and a segment of the population disperses into new territories. Sinks occur when these new territories offer suitable habitat. However, fecundity rates are insufficient to balance mortality rates (Pulliam, 1988; Watkinson & Sutherland, 1995; Perkins et al., 2003). In this case, skinks are taken by avian predators prior to their ability to breed.

Although there is some evidence to suggest that birds preferentially take juvenile lizards (Poulin et al., 2001), results in this study indicated that avian predators do not discriminate. However, there tended to be some preference seasonally, particularly during summer; when sub-adults may be targeted.

When predators focus on a group belonging to one part of a life cycle, there can be repercussions for the survival of the species. For example, predators in the Serengeti, specifically target juvenile cheetahs Acinonyx jubatus to such an extent that the overall cheetah populations declined (Durant et al., 2004). It is, therefore, possible that birds targeting sub-adults could have a negative effect on skink numbers overall.
Sub-adults were more common in edge areas (Anderson & Burgin 2003). This was probably due to this life cycle stage dispersing. During summer, when this phenomenon occurred most frequently, the abundance of sub-adults in edge areas would be such that it is more likely for them to be taken in larger numbers. In this regard the edges appear to be acting as a sink, while core areas are the source. Studies on gravid female *L. guichenoti* have indicated that they move slower than non-gravid individuals (Qualls & Shine, 1997; Shine, 2003). This would impact on their ability to flee predators. Birds may, therefore, preferentially target these females before egg laying. This could also impact on skink numbers, particularly in those females attempting to nest in edge areas.

Approximately 29% of all attacks were targeted directly to the tail region of the decoys. This result was not expected, as one of the major predator avoidance tactics employed by skinks is tail shedding, which maximises their opportunities to escape. The incidences of tail attacks would leave the skinks susceptible to future predation. For example, Downes and Shine (2001) determined that after tail shedding *L. guichenoti*, became slower, making them vulnerable to snake predation.

Tail loss also means the loss of an anti-predation mechanism. Skinks are therefore, more vulnerable to future predation. Such vulnerability has been recorded in turtles. Both loggerhead *Caretta caretta* and green turtles *C. mydas* have been reported to turn their carapace towards the biting mouth of a shark, as they attempt to manoeuvre out of the way. This often leaves the shell damaged and exposing parts of the turtle body (Marquez, 1990). As a result, turtles are more vulnerable if confronted by a similar predator (Heithaus *et al.*, 2002).
Unsuccessful predation attempts can have other adverse effects on prey. For example, a study conducted on elephant seals *Mirounga angustirostris* demonstrated that the female seals had a marked decrease in reproduction rates after failed shark attacks (Le Boeuf *et al.*, 1982). Gravid female lapwing birds *Vanellus vanellus* that escape a predation attack are also more likely to lay infertile eggs than those not exposed to such attacks (Galbrith, 1988). The closest study on such affects in lizards, demonstrated that failed predation, or successful escape, of the ovoviviparous lizard *Lacerta vivipara*, induced high levels of corticosterone into the eggs of the females, which resulted in reduced body size and condition of neonates (Uller & Olsson, 2005). Skink reproductive success could be hampered, especially if such a failed attack occurred during spring. As Downes and Shine (2001) have indicated that shedding tails slow skink movement, it could limit reproductively viable adults in finding and copulating with a mate.

Failed attacks often leave the prey wounded and vulnerable to disease. For example, threespine sticklebacks *Gasterosteus aculeatus* that were left wounded by predators had a 30% greater risk of contracting disease than those unharmed by attempted predation (Reimchen, 1994). Further there is evidence to suggest that a wounded area may remain weakened after escape from predators. For example, damaged shells of the periwinkle snails (*Littoraria irrorata*), remained weak even after regeneration and this left them vulnerable to future attacks (Lewis & Eby, 2002).

Skinks that escape predators may, therefore, be left weakened since losing their tails equates to loss of fat storage (Alibardi, 1995) and even after tail regeneration, they remain more vulnerable to attacks. Downes and Shine (2001) indicated that tails that
regenerated were smaller and could be malformed, thus not being as effective in storing fat, or they may not shed as easily as the original tail when attacked. This would certainly impact on a skink's ability to survive post-attack.

Overall it would appear that skink distribution within the remnants of this study was being adversely affected by over predation in edge areas.
Chapter 8. Final Discussion

This study focused on the interactions between small skinks and their major predators/competitors (birds) and prey (arthropods) in core and edge areas of remnant Cumberland Plain woodlands. These groups have been reported to be adversely affected by edges, and this has to lead to changes in their abundance and diversity in remnant areas (e.g. Berry, 2001; Davies et al., 2001; Anderson & Burgin 2002). However, in the small-sized remnants of open woodland studied, the three groups investigated demonstrated different responses to edge habitat, and this impacted on the interactions between them, the most negative occurred between predatory birds and small skinks.

Of the three taxa, only arthropods appeared to maintain a similar abundance and diversity between edge and core areas (Table 8.1). Birds and skinks were either in lower numbers in the perimeter areas (skinks) or were interior/perimeter specialists (birds). Based on these data the obvious question is why and how does this impact on their interactions?

Table 8.1. Distribution of animal groups across remnants and adjacent areas. Lines represent presence in relatively greater numbers (▬), presence in fewer numbers than elsewhere (---), and absence (  ).

<table>
<thead>
<tr>
<th></th>
<th>Adjacent matrix</th>
<th>Edge</th>
<th>Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthropods</td>
<td>----------------</td>
<td>---------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Small skinks</td>
<td>----------------</td>
<td>--------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Predatory birds</td>
<td>----------------</td>
<td>--------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Large competitive birds</td>
<td></td>
<td>--------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Small birds</td>
<td>----------------</td>
<td>--------------</td>
<td>---------------</td>
</tr>
</tbody>
</table>
Differences in habitat quality between the core and edge may influence distribution of taxa throughout a remnant (e.g. Matlack, 1993; Young & Mitchell, 1994; Harper et al., 2005). For example, studies as diverse as those conducted on arthropod assemblage in habitat fragments of moss in the United Kingdom (Hoyle & Harborne, 2005), woodlands in Western Australia (Abensperg-Traun & Smith, 1999), and orchard meadows in Germany (Steffan-Dewenter, 2003), concluded that the major causative factor of changed diversity between interior and perimeter appeared to be a lack of adequate habitat resources available in edge, compared to core areas.

The remnants utilised in this study have not changed significantly in more than 20 years, nor have they been exposed to substantial human disturbance during this time. This has resulted in the vegetation structure being similar throughout the remnants, resulting in comparable microhabitats across edge and core areas. Both edge and core habitat elements have been shown to be similar at least for skinks (Anderson & Burgin 2002). The variables measured could have been examined for other taxa (e.g. litter depth, canopy cover, ground cover percentage) as they are also required for other species (Adam, 1994; Watson et al., 2004). However, other abiotic factors, for example microclimate fluctuations, may create variations between core and edge habitats.

Microclimatic shifts between core and edge (e.g. air temperature, light intensity) have been linked to changes in both the abundance and diversity of plants (e.g. Soulé et al., 1991; Williams-Linera et al., 2005), and faunal assemblage (e.g. Bromham et al., 1999; Davies et al., 2001; Foggo et al., 2001). Most such studies have
determined that edge areas experience harsher climatic conditions (e.g. higher temperatures, more wind shearing) that prevent some species from inhabiting these areas, while favouring others. For example, Gray et al., 2004) determined that some amphibians cannot maintain high numbers in edge areas because these areas are more exposed, and thus drier and hotter. However, these studies have been conducted in either closed woodlands (e.g. Lyon 2002) or tropical rainforests (e.g. Laurance & Laurance 1999), where dramatic alteration or removal of trees and understorey could create immediate and long term microclimatic effects. For example, the impacts of removal of canopy cover in rainforests resulted in a decline in seedling survival due to altered micro-climate conditions (i.e. increased temperature, light intensity; Turner, 1990).

The remnants utilised in this study were open woodlands. These areas are categorised by sparsely placed trees, less foliage protection then closed forests, and there are often bare patches between vegetation stands. This type of habitat often has pockets of fluctuation in microclimatic conditions, even before fragmentation, and endemic inhabitants (such as the majority encountered in this study) of these areas are adapted to such variations (Specht et al., 2006). Baiada (2002) examined various factors (e.g. light intensity, air temperature) relevant to microclimate dynamics within the study sites. While, as expected, he found that there were pockets of variation, overall the core and edge areas could not be distinguished on the bases of microclimate. It is unlikely, therefore, that microclimate fluctuations were a causative effect on the pattern of taxa distribution observed in this study.
Another affect that impacts on taxa diversity throughout remnants is the size of the remnant (Higgs & Usher, 1980; Margules, 1987; Merriam & Catterall, 1991; Miller et al., 1997; French et al., 2000; Jordan, 2000). It has generally been observed that larger remnants have greater ability to mitigate effects emanating from the edge (Saunders et al., 1991; Rankmore & Price 2004). Evidence obtained by Campi and Mac Nally (2001) supported this observation. They determined that bird assemblage in large remnants where distance from edge can exceed 2km, displayed little variation between perimeter and interior. They speculated that remnant size was the mitigating factor that enabled the ecosystem to stabilise, neutralising any edge effects.

Some taxa do not appear to maintain diversity in small remnants (i.e. areas ≤ 200 ha). For example, there have been reports of decreased diversity of avian (e.g. small honey eaters; Catterall, 2004) and endemic mammals (e.g. R. fuscipes and A. stuartii; Dunstan & Fox, 1996) within small remnants. The authors speculated that in small remnants the more ‘aggressive’ or opportunistic species tend to dominate (e.g. M. melanocephala and R. rattus), and force the more timid or specialist species to retreat. A similar observation was recorded within the sites of this study, and was most pronounced within the avian assemblage. Larger aggressive birds dominated edge areas, while the smaller more timid birds were not excluded from the remnant but they were restricted to the core areas, and displayed core specialist behaviour.

Hofer, et al. (2004) determined that inhabitants of small remnants were adversely affected by edge impacts and this impacted on abundance and diversity of the individual taxa which would, in turn, presumably change the dynamics of the species
interactions. Based on the size of the remnants (<176ha) examined in this study, this pattern would be expected and it was observed in the distribution of birds and skinks across the edge and core. However, arthropods did not display the same pattern, and there has been evidence that these taxa are more likely to be effected by the age of the remnant than by the size.

The age of these remnants (>100 years), and the approach to management that effectively leaves them undisturbed by local agricultural or urban impacts, may nullify any adverse edge effects (Barrett et al., 2003). This hypothesis was supported by Gibb and Hochuli (2002) who studied heathland remnants within Sydney. They demonstrated that smaller fragments displayed greater similarity in arthropod diversity throughout than larger ones. This may be a general trend since comparable results have been reported on arthropod diversity in Europe (e.g. Tscharntke et al., 2002) and North America (e.g. Summerville et al., 2003). In this study the arthropod populations encountered throughout the study remnants demonstrated little if any ill effects from edges or the impacts were such that they were equivalent across the whole remnants. Whatever the reality, these taxa best modelled the hypothesis of age nullifying edge effects (Table 8.1).

After initial fragmentation and in the absence of continued disturbance (i.e. further fragmentation through land clearance) arthropods can recolonise, and reach equilibrium, relatively quickly, compared to vertebrate species. For example, aerial arthropod diversity steadily increased over a period of 2.5 to 3 years, after fragmentation of peatland forests, to almost similar pre-disturbance levels. However, abundance of some species (e.g. aphids) declined. It was proposed that while
diversity may quickly rebuild, population size of some species may take longer to peak, if ever (Deans et al., 2005). Overall, it would appear that arthropods are able to overcome edge effects and utilise these areas similarly to the core. This was further demonstrated when arthropod distribution was examined based on skink preferred prey. This sub-set of arthropods was similarly distributed between core and edge areas of the study remnant. It was, therefore, concluded that lack of food resources did not contribute to the observed pattern of skink distribution.

In the remnants of an age and size of those studied, it is possible that there is no longer a micro-habitat difference between core and edge (Baiada 2002). Such effects have been suggested by Hochuli et al. (2004) who determined that some arthropod species treat small remnants as edge, and thereby equivalent diversity can be maintained throughout the remnant. The pattern of arthropod distribution I observed could be explained in these terms.

Bird distribution throughout the remnant followed a different pattern to arthropods, in that abundance and diversity was dissimilar in core and edge areas. The primary delineating factors in their distribution were behaviour and size; with large aggressive birds dominating in edge areas, while smaller species were observed only in the interior areas of the remnants.

This model of distribution has been reported in previous studies. For example, Keast (1995) determined a correlation between large aggressive birds and edge habitats. The author also indicated that where anthropogenic structures and gardens abutted the remnants or were in close proximity to the remnants, an overabundance of large
birds is likely to occur. Campi and MacNally (2001) concurred with these findings but extended the link to include adjoining agricultural land. The post-agricultural land and gardens surrounding the study sites were utilised by large birds in conjunction with the edge habitat by the large birds encountered in this study, although I observed that most of these birds, e.g. *G. tibicen*, preferentially used fences and roof tops. This could be due to the sparseness of large trees growing in these areas, compared to the remnant.

The most likely birds to dominate edges near human infrastructure are the “Aussie Icons” such as *G. tibicen*, *M. melanocephala* and *Co. coronides* (Catterall, 2004). These birds are major predators of small skinks (Barker & Vestjens, 1984a; Marchant & Higgins, 1990; Higgins *et al.*, 2001), but their range includes areas external to the remnants. Many of these birds are encouraged to visit local urban gardens by supplementary feeding (estimated between 38 and 57% of householders throughout eastern Australia (McLees, 2000; Rollinson *et al.*, 2003), ‘bird friendly gardens’ and nesting sites (Catterall, 2004; O'Leary & Jones, 2006; Parsons *et al.* 2006). These birds cross-forage between the endemic remnants and the adjacent urban and agricultural areas, and incorporate the whole landscape matrix into their home range, and have the potential to increase their numbers more efficiently than species that continue to rely only on the remnants (Catterall *et al.*, 1991).

The edge birds of this study were able to extend their territories into the surrounding matrix and incorporated urban and rural infrastructure (e.g. fences, powerlines) into their daily activity. Use of such structures at the edge of the remnant, could enhance their ability to view prey within the edge of remnants, and thus increase the potential
to prey on smaller remnant inhabitants. These birds also appeared to be less impacted by the removal of native vegetation because of their ability to utilise human areas (Parsons et al., 2006). Major et al. (2001) suggested that it was the presence of created environments that attracted these birds into the edges of remnants, but it was their aggression which permitted them to remain for extensive period.

Coupled with their behaviour and size, the birds observed in this study also appeared to favour core and edge areas based on their foraging mode. For example, the species encountered in edge areas, and adjacent agricultural and urban ecosystems, were by definition either predominately terrestrial foragers (e.g. Co. coronides) or aerial/terrestrial hunters (e.g.; G. tibicen; Barker & Vestjens, 1984a). Conversely, the majority of the avian species encountered in the core were arboreal/aerial foragers, nectarivorous or granivorous (e.g. N. temporalis, H. nigricans; Pizzey & Knight 1997). Bird foraging behaviour (terrestrial, aerial or arboreal) appeared to be an important factor in determining habitat usage in this study.

Other behavioural strategies employed by birds that dominated the edge may act as a deterrent to the smaller birds. Most of the edge species displayed some form of threatening behaviour that deters competition. For example, M. melanocephala are known for their aggressive behaviour towards interlopers within their territory (Põldmaa et al., 1995; Major et al., 2001). They utilise both noise and swooping attacks to defend their territory. Both of these behaviours are designed to intimidate and displace potential competitors (Piper & Catterall, 2003). Other anti-competition tactics utilised by birds include flocking (e.g. egrets; Wahungu et al., 2003) and screeching (e.g. C. roseicapilla; Heinsohn et al., 2003). In addition, some of the
larger birds (e.g. *D. novaeguineae*) prey on these smaller birds, their eggs and/or hatchlings (Prizzey & Knight 1997). The generally more aggressive nature of most of the birds that inhabited edge areas was considered to be a major factor in the distribution of birds throughout the remnants, due to their ability to incorporate surrounding areas into their territory, and their ability to defend their territories.

In contrast, the small skinks that occur in greatest abundance in the woodland remnants studied are considered habitat generalists. They are able to re-establish after major disturbances such as mining (e.g. Twigg & Fox 1991), and logging (e.g. Lunney et al., 1991. They are also able to cope with anthropogenically created areas, including urban gardens (Burgin, 1993), provided there are sufficient foraging, basking, shelter, and breeding sites for the skinks to survive successfully in an area (Mather, 1989). As previously discussed there is appropriate habitat within the study area, and therefore, it is more likely that the distribution pattern observed in the skinks was predation due to a break down of ecosystem functioning due to the overabundance of competitive and predatory birds in edge areas.

Most of the birds observed in the edges utilised similar foraging niches (i.e. terrestrial foraging) as the endemic small skinks. Although not directly competing for food, the overabundance of these birds, coupled with the threat of predation by many of these bird species, could result in skinks modifying their foraging behaviour so as to avoid adverse encounters. For example, Hofer et al. (2004) suggested that lizards altered their foraging time in ways that avoid potential threats from birds; however, due to reptiles being ectothermic, such avoidance cannot be sustained. Regardless,
modification of foraging behaviour by skinks may be possible if birds were the only predatory threat within an area.

The remnants examined in this study are inhabited and/or visited by other skink predators, such as snakes (e.g. *Pseudonaja textilis*; White & Burgin 2004), domesticated dogs and cats. Although these predators are not restricted to hunting in one area of the remnant, their presence coupled with an increase in predatory bird abundance, could increase the overall predation on skinks in edge areas. Further, when predation rates on skinks were measured, birds preyed on small skinks in greater numbers in the perimeter woodland remnants than in the interior. This predation pressure was sustained throughout the year.

Under such circumstances, edges may be an ecological trap for small skinks. An ecological trap can exist in areas that attract dispersing animals with suitable environmental cues (i.e. adequate habitat and food), but actually increase their risk to attack by predators (Pulliam, 1988; Namba *et al*., 1999; Kristan, 2003). Ultimately the population could face localised extinction, due to increased mortality rates (Battin 2004).

The suggestion that the edges in these remnants could be ecological traps has some credence. Anderson and Burgin (2002) reported that edges had a larger population of sub-adults, than either juvenile or adult skinks. These results could indicate that either edges lack suitable habitat elements for all ages, or predation rates are high. In this study neither food (arthropods) nor abiotic factors, such as habitat requirements (basking, foraging and refuge sites; Anderson & Burgin 2002), and environmental
conditions (e.g. microclimate, light penetration; Baiada 2002) were observed to be limiting factors. It is, therefore, concluded that the lower numbers of skinks in edge areas is a result of on-going predation pressure.

Over predation in ecological traps can have a myriad of effects on populations. The constant depletion of numbers stunts the evolutionary development of new anti-predator behaviour. For example, over predation of primates in areas of Africa, has prevented them from adjusting their behaviour to reduce predation risk (Hill & Dunbar, 1998). The implication is that inherited behaviour, and even the gene pool, could become stagnant, rather than progressive. This could also occur with small skinks, particularly if predators, such as birds, targeted gravid females, prior to clutching.

Ecological traps also prevent dispersal from the ‘trap’ into appropriate landscapes (Battin 2004). In areas such as edges, where dispersal can meet with a number of hazards inherent in this type of environment (e.g. barrier effects), the addition of increased mortality rates would make successful dispersal from the perimeter even more difficult. Similarly, the same vulnerability would be experienced by externally (i.e. skinks from other habitats) dispersing skinks attempting to enter the remnant via the edge. For example, some taxa are unable to transverse a gap of 30 to 40 m (dung and carrion beetles; Klein, 1989) between suitable habitats. Others are inhibited by larger expanses (80-150 m; Laurance et al., 2002). In this study skinks attempting to enter the edges of the remnants in this study via the surrounding matrix, must also contend with increase risk of predation. No skinks were observed within the adjacent post-agricultural land, and this would imply that these remnants are
effectively islands. The consequence is that edges may be reliant on recruitment of dispersing skinks from the core of the same remnant rather than from unconnected remnants or the matrix surrounding the edge.

Anderson and Burgin (2002) determined that sub-adults were more likely to be found in edge areas, compared to hatchlings and mature adults. This occurs usually as sub-adults attempt to establish new territories away from competing adults (Banks et al., 2005). It is likely that sub-adults radiate out from the interior towards the perimeter of the remnant where they remain ‘trapped’ and possibly preyed upon prior to becoming reproductive. This may account for the lower occupation of adults (sub-adults not being able to reach maturity) and juveniles (no hatchlings) within perimeter areas (Anderson & Burgin 2002).

The information gained from this study may also help explain the difficulties faced by other lizard species in remnant areas. For example, many of the larger lizards (e.g. lace monitors, eastern blue tongue lizards) are being lost throughout remnant areas, including those examined in this study (Driscoll 2004; White & Burgin 2004). While there are a number of factors that have been linked to the decline of these lizards (e.g. habitat loss; Jellinek et al. 2004), it is possible that they are facing their own version of over predation by over-abundant predators. The conclusions that aggressive and/or predatory birds were most likely to be the cause of low numbers of skinks in this study, could be used as a catalyst to examine the predation rates on their larger relatives.
In summary, this study has demonstrated that old, small remnants not continually exposed to major disturbances (e.g. logging, agricultural practices) can re-establish stability in terms of environmental conditions. However, a stable environment or a single taxonomic group does not necessarily predict the response individual taxa will have to edge habitats and that this can alter the interactions between dependent groups such as prey/predator or competitors.

In the remnants examined in this study arthropods demonstrated similar population structure between the core and edge areas. Based on previous studies (e.g. Gibb & Hochuli, 2002) it was concluded that these taxa could nullify adverse edge effects over time (Barrett et al., 2003), or were more likely to respond to the remnant as if it were either all edge or all core habitat (Hochuli et al. 2004). That is, they perceive no habitat difference.

Avian responded to edge and core areas by segregation based on behaviour and size. Similarly to other studies (e.g. Keast, 1995; Campi & Mac Nally 2001) large aggressive birds dominated the edge of the remnant, while small, more timid birds were only encountered in core areas. This delineation occurs despite the presence of adequate habitat to accommodate both sets of birds throughout the remnant. Generally it is believed that segregation occurs for two main reasons 1) the large birds are able to incorporate the surrounding matrix into their foraging behaviour (Catterall et al., 1991); and 2) the aggressive nature of these birds means they are more able to defend their territory from interlopers (Major et al., 2001).
Small skinks were encountered in both core and edge areas. However, their numbers were greatly reduced in perimeter areas. Again, this is in spite of the similarity of abiotic conditions and food resources in both core and edge areas of the remnant. The evidence obtained in this study indicated a negative effect between skink numbers and the increased abundance and activity of aggressive and predatory birds within the perimeter regions and indicated that over predation on skinks is occurring within these areas. It was concluded that the edge areas of these remnants act as an ecological trap. It was further concluded that while there was adequate resources available within edge areas, skinks would continue to be attracted to the area, despite the risk.

This study provides for a greater understanding of over abundance of predators within a small remnant and provides an indication of how this may impact on other species, such as the larger skinks that are also likely to be under threat from an increasingly fragmented landscape.


210


Christensen, P.E.S. (1980) The biology of *Bettongia penicillata* (Gray 1937) and *Macropus eugenii* (Desmarest 1917) in relation to fire. *Forests Department of Western Australia Bulletin* **91**.


Review of the ecology of Australian urban fauna: a focus on spatially explicit

landscapes of the central Appalachians. In *Wildlife and habitat in managed


microclimate edge effects in tow mixed-mesophytic forest fragments. *Plant Ecology*
**147**: 21-35.

German, P. (1986) Communal egg laying in the Weasel Skink (*Lampropholis

large and small fragments support different arthropod assemblages. *Biological
Conservation* **106**: 91-100.

Press.

Goldingay, R., Daly, G., and Lemckert, F. (1996) Assessing the impacts of logging
on reptiles and frogs in the Montane forests of southern New South Wales. *Wildlife
Research* **23**: 495-510.


selection by copperskink skinks (*Ctenotus taeniolatus*) from sandstone outcrops in

structure on a Southern High Plains, USA, amphibian assemblage. *Landscape


Ross, K.A., Fox, B.J., and Fox, M.D. (2002) Changes to plant species richness in forest fragments: fragment age, disturbance and fire history may be as important as area. *Journal of Biogeography* 29: 749-765.


