Avian species abundance and richness in a variably urbanised landscape in Wellington City, New Zealand

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A thesis submitted as partial fulfillment for the degree of
Master of Science in Restoration Ecology
Victoria University of Wellington
2008

A Wellington thrush, *Turdus philomelos* at home. Photograph by Andrew Gorrie, originally featured in the Wellington Dominion Post, August 2008

Urban innovation

Abstract

Avian community composition fluctuates across the landscape at different scales of space and time. These fluctuations may be modified at the broader scale of landscape and at the local scale of habitat patch. A species' ecology also influences its occurrence and abundance in the landscape. This thesis investigates the spatial and temporal distribution of the avian community in Wellington. Wellington is an interesting case study because it has a diverse range of landscapes influenced by the proximity of hills to the coast (see Appendix 3). I assess the effect of landscape classification on the richness and abundance of birds and the role of fine patch structure in shaping this distribution. My study was located within a 5-km radius of Wellington City's central business district (41° 16' S, 174° 46' E). I used six strip-transects divided into 400m length segments that traversed through high to lower density residential suburbs and green space inter-digitated with built habitat, and established five-minute count (FMBC) points at each segment interval along these routes for a total of 49 points. I used ArcGIS to analyse the habitat patch types in the 100-m areas surrounding the FMBC. I recorded avian species type and abundance along the strips and at the FMBC during the morning and evening. A total of 35 bird species and 10966 individuals were recorded along the strip-transects and 34 bird species and 5960 individuals at the FMBCs. House sparrow, then starling and black-backed gull, rock pigeon, blackbird and silvereye were the most common and widely spread species. Results indicated that landscape type modified avian biodiversity with the highest number of species (S) recorded in green landscapes (n = 10, S = 15.9) and the lowest in wharf littoral (n = 2, S = 7.5) and low-density commercial sites (n = 3, S = 6.67). The diversity of the landscape within an area did not influence avian biodiversity. I found that total species abundance did not change across the landscape but that the

species' ecology did influence where it occurred and its abundance in the landscape. Dietary diversity particularly influenced a species' abundance. Both season and time of day altered species richness and abundance, with lower values of richness recorded in autumn (morning period = 13.5, evening period = 10.7). I found that avian communities in the Wellington urban area were dominated by six common species but that many more species were present in much lower numbers at fewer sites. Results showed an inverse relationship between species richness and abundance – while the greater biomass (abundance) of birds concentrated at FMBC within the built commercial centre and surrounding higher density housing areas, richness increased with distance from the built centre to residential and green sites. I found no relationship between species richness and the total number of individuals present at any point, and the total biomass and abundance of birds was also independent of patch size. Neither habitat patch diversity nor average patch size influenced species diversity across the community of birds, but the effect of average patch size was less at patches between 300 and 1500 metres. The abundance of some individuals in their favoured patch type did vary in response to patch structure with the strongest relationships seen for blackbird and house sparrow. These results suggest that birds are responding to cues at the larger scale of landscape first rather than to fine patch structure within the urban setting, and therefore that landscape is a more important influence in driving bird biodiversity.

Acknowledgements

I have many people that I would like to thank for their assistance, support ideas and understanding – all of them made this thesis possible and rewarding.

Primarily I would like to thank my supervisors Dr Wayne Linklater and Dr Stephen Hartley for the time they have invested in me and for encouraging me through the occasions I felt defeated. I particularly thank Wayne for being firm and Stephen for helping me find my way around the Excel programme and ArcGIS.

I sincerely thank Dr Murray Williams for always leaving his door open, for his helpful tit bits of information and for introducing me to the fascinating field of restoration ecology in 2006.

Thanks also to: the Student Learning Centre, Deborah Laws and Ann Pocock for strategy with writing, and Xiaodan Gao for formatting. I particularly thank Sue Hirst, reference librarian and EndNote specialist. I would also like to thank my colleagues Francis Forsythe and Monica Awasthy for their friendship, encouragement and sharing of knowledge.

I acknowledge the contribution made by the Wellington City Council, Knowledge Solutions team – Andrew Shakes and Nenad Petrovic for providing high-resolution maps of Wellington, and the Greater Wellington Regional Council for other map material.

Lastly my special thanks and appreciation goes to my family, particularly to my partner Gerald for his enduring and staunch support. I could not have completed this thesis without him. I thank my sons Jamie and Samuel, who although busy themselves, were always there for me. And I especially appreciate my friend Diana McCrae who did not let me give up. Thank you to you all.

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Chapter 1: General Introduction and overview

General Ecology Theory

Modern ecological principles like the equilibrium theory of island biogeography (MacArthur & Wilson 1967) and the associated understandings about the influence of fragmentation and habitat loss were largely developed and studied in wild or natural environments. MacArthur and Wilson put forward their theory in 1967 based on observations of how species colonised vacant oceanic islands and reached equilibrium. They concluded that immigration of new species was ongoing while resident species became extinct, depending on island size and distance from sources of emigrants. The net effect was neither a gain nor loss in the number of species from islands at equilibrium (Bunnell 1999).

In the ecology of natural landscapes, island biogeography theory suggests two important influences – area or size of a patch and distance from an emigrant source. The effect of area is directly equivalent to the fragmentation of habitat. Put simply, larger areas of habitat have more potential niches, and therefore a greater receptivity for a variety of species (Bunnell 1999). Thus when a habitat is fragmented it supports fewer species. Smaller ‘islands’ of habitat have lower populations due to the greater occurrence of extinctions. The second property of distance is intricately bound with the concept of connectivity and therefore movement. The more isolated or distant fragmented patches are from potential source populations, the less common emigration of species will become. Extinction rates remain the same and reduced emigration can lead to localised reduction in species numbers.

Habitat loss is accelerated by urbanisation that fragments habitat. Thus the two processes; fragmentation and habitat loss are linked and occur concurrently (Fahrig 1999; McComb 1999). Habitat fragmentation at the level of landscape, describes the distribution of pieces of habitat, not the total area and the best habitat is spatially concentrated in patches (Bunnell 1999). The process of fragmentation has profound consequences for patch size. The size of patches becomes smaller with increasing fragmentation. Alternatively, habitat loss on its own can both decrease patch size and increase degree of isolation (Fahrig 1999) because larger remnants that are not broken up may be further apart**.** The implications for species conservation are different and not always straightforward depending on which process is dominant. Thus if a species is threatened because of habit loss the solution is direct: conserve and restore habitat. When fragmentation is implied the treatment may be to restore just enough habitat to connect the broken pieces of remaining habitat (Fahrig 1999) and thus to downplay the larger effect of habit loss on species survival. The application of island biogeography theory to urban habitat patch dynamics may apply when landscapes can be separated into suitable and unsuitable habitats (Melles et al. 2003), as is the case with islands surrounded by sea. However the difference is that urban habitats are only altered. Even the poorest habitat may still offer foraging and shelter opportunities (Melles et al. 2003) and therefore are not hostile to all species. Patch size, location in relation to surrounding landscape and degree of connectivity to areas of similar habitat, are nevertheless still important.

Community Ecological Theory

Within an ecological community an organism (or population) interacts with other individuals and with the biotic and abiotic elements that form its habitat. The term niche describes these relationships and the interplay that occurs between the individuals and the

relative abundance of resources and or competitors within that system. The concept is limiting in that within a niche competition for the same resources must occur, and therefore no two species can co-exist in a given niche for a long period.

It is important to understand more about how organisms select habitat and at what level they respond to landscape structure. How birds perceive area and objects in the landscape is thought to determine their use of that habitat. This in turn is governed by their own natural history – feeding and nesting requirements, body size, and community relationships. Thus the common house sparrow (*Passer domesticus*), a granivorous ground feeder that nests in crevices, prefers urban settings despite the prevalence of suppressive factors such as vehicular and pedestrian traffic and the greater exposure to predators. In avian communities the balance and density of populations are therefore regulated by a combination of feeding type and foraging habit, nesting type and sociality (Emlen 1974). The quality of the habitat for food, water, nesting, and resting are also vital (Emlen 1974). Documented foraging guilds include seed, insect and nectar feeders. Also relevant to habitat quality for insectivores is whether insects are taken from the ground, tree trunk or tree foliage, or in the air. All these features are altered by the establishment of urban areas and the measure to which birds can survive the disturbed conditions determines their density, distribution and diversity in cities.

Urban Ecology – the global context

Human populations are growing globally. By 2050 the world population is projected to increase by 2.5 billion (United Nations. Population Division of the Department of Economic and Social Affairs 2007), to 9.4 billion. Much of this increase will occur in urban areas (United Nations. Population Division of the Department of Economic and Social Affairs 2004) with some projections placing the worldwide urban population at 5

billion (Gaydos & Clarke 1998). The tendency to urban growth is more pronounced in developing nations where human populations will rise from 5.4 billion in 2007 to 7.9 billion by 2050 (United Nations. Population Division of the Department of Economic and Social Affairs 2007).

The impact of human activities on the environment has been major. There are no ecosystems on Earth's surface still free of pervasive human influence (Vitousek et al. 1997). The growth of cities and the process of urbanisation worldwide has been a predominant cause of species extinction (McKinney 2006). This pattern is likely to continue, more so in developing countries where human impact on ecosystems will be further exacerbated due to the faster pace of urban growth (Marzluff & Kern 2001), with local governments having first to meet the basic needs of much increased urban populations within cities that have limited infrastructure.

Historically urban areas have been less considered as biological environments but more recently it has been appreciated that they are part of a continuum at one end of a gradient, ranging from natural wild lands to rural, suburban and urban centres (Blair 2001). Intensely urban environments are uniform throughout the world (Clergeau et al. 2006); they are relatively simple with less complicated food webs, strong abiotic influences and imported food subsidies (Rebele 1994). The dominant features of cities include: the majority of their land surface is permanently covered by pavements or buildings – above 80% at the urban core (Blair & Launer 1997)**,** the increased amounts of energy they use and create, the amplified productivity they make available and, because of their altered state, the wide variety of environmental conditions they exhibit (Rebele 1994).

Because most cities exist in a state of permanent flux the altered environment does not have enough time to equilibrate through succession before being modified again

(Rebele 1994). This makes the accepted theories of stability and equilibrium inadequate for interpreting their systems (Rebele 1994). It might therefore be debated that ecological 'rules' such as those driving diversity, density, dispersal, and distribution in urban areas are different from those of more natural landscapes.

The conditions that make cities unique include: (1) the occurrence of local conditions of extinction, dispersal and migration (Rebele 1994) and (2) localised climatic conditions. (1) Because remnant unmodified habitats (patches) are often small and embedded within a highly disturbed matrix (the surrounding urban landscape) they are continually open to colonization by non-native species. This compromises their ability to sustain native species that find it more difficult to compete and so they become extinct. (McKinney 2002). The higher population density of the urban core increases the importation of non-native species and exacerbates the process. Thus, more widespread weedy species of plants, and human dependent, commensal species of birds replace natives (McKinney 2002). Because cities globally tend to reflect similar conditions, the same urban adapted species are present in almost all cities. This results in homogenisation of species across cities with fewer species being present overall. (2) Localised conditions of climate. The increase in surface area of impervious materials such as concrete, glass, metal and brick change ambient conditions locally (Berry 1990). In cities temperature, precipitation, cloudiness and pollution increase (Landsberg 1981). Also, wind speed and radiation are less than the surrounding rural areas (Berry 1990). The heat island that results from these altered conditions alters city ecosystems. Together with the increased productivity (in the form of subsidized water and fertilizer regimes), as well as the increased availability of food (human refuse and supplementary feeding) this makes cities generous and often less harsh ecosystems for a wide array of individuals that includes more urban tolerant birds coined 'urban exploiters'. Urban exploiters comprise a small

subset of the world's species that are highly adapted to the altered urban conditions. They are generally commensals that have become largely dependent on human subsidies or the increased productivity that accompanies human settlement (McKinney 2002).

Nevertheless urban environments with artificial habitats also comprise patches of rich and diverse natural vegetation as well as unmanaged abandoned sites. Like other less modified environments, these areas settle and undergo succession. Careful planning can ensure that distant patches of less disturbed habitat are connected through corridors, such as tree-lined streets, areas of lawn, and suburban gardens. The same criteria that govern the effectiveness of corridors in wild landscapes seem to apply. For example, for birds in urban landscapes wooded streets are transitional in their suitability as habitats for movement, feeding and nesting (Fernandez-Juricic 2000). Likewise research on the role of patch size indicates that the size of remnant habitat patches does matter. For introduced birds larger patches support a greater richness and have quite different communities of birds than smaller remnants (Antos et al. 2006). In fact, the comparison of urban landscapes with its mix of habitat loss and fragmented remnant habitats to island biogeography seems appropriate, thus arguably a habitat island approach to conservation of birds in these landscapes would be plausible.

Effect of urbanisation

The interaction of different elements within urban systems varies with the nature of land use both temporally and in space. Land use dictates amount and type of land cover but the length of time a fragment is maintained within the surrounding dominant landscape, as well as its size, strongly influences the composition and abundance of its flora and fauna. Urbanisation modifies landscapes by changing resources such as food, water, perches, roosts, and nesting sites (Emlen 1974; Mills et al. 1989). The degree of disturbance

impacts that change. Hence moderate development increases ornamental vegetation, water supply, primary productivity and the area of edges (Blair 1996). The degree to which birds can exploit these novel environments will determine peak densities and/or richness in any given area.

Earlier research findings describe three general effects of increasing urbanisation on avian fauna (Blair 1996): (1) species composition change, (2) species numbers decrease and (3) species abundance increase. These patterns in fact reflect the depth of disturbance that parallels urban development. In an attempt to further clarify these patterns Blair (1996), studying land use and avian diversity along an urban gradient, found a divergence from these patterns. He showed that Shannon diversity (Shannon & Weaver 1963), species number, bird density, and bird biomass all peaked at intermediate levels of urbanization rather than at less modified sites or, when considering bird biomass, at the most urban site (Blair 1996). This is called the intermediate disturbance hypothesis and in cities modified green spaces may represent this intermediate disturbance between unmodified habitat and the highly modified urban habitat. Blair's results allude to the complexity of patchy urban environments that are best studied in terms of the disturbance level and degree of structural diversity offered by the site and the utility of the intermediate disturbance hypothesis (Blair & Launer 1997; McKinney 2002) in urban environments.

Fauna, flora and biodiversity in the urban environment

As ecosystems, large cities have more in common with other cities than with their surrounding regions. Thus the typical urban bird biomass is non-native to its region but common to all cites. Some birds like the feral dove (*Columba livia*), reflect a degree of pre-adaptation to the vertical concrete features of cities, but both these and

the more abundant species such as house sparrow (*Passer domesticus*) and European starling (*Sturnus vulgaris*) now emigrate from other urban regions (McKinney 2006). These birds, dubbed 'urban exploiters' are adept at exploiting both food and shelter provided by humans (McKinney 2006) and reach their highest densities in developed sites (Blair 1996).

Many species more sensitive to human induced changes are more abundant in increasingly undisturbed sites. This latter category includes many native bird species that are present more or less to the extent that native vegetation is present or reduced (Blair 1996). A management challenge exists in that each of these species has adapted in a particular way to the modified habitat (McKinney 2006). In New Zealand the whitehead (*Mohoua albicilla*), a lower canopy native, has shown its flexibility by adapting to some exotic pine plantations, particularly where there is a developed understorey of native shrubs (Heather & Robertson 1996). A third species type, which Blair (1996) calls suburban adaptable, is able to exploit the additional resources such as ornamental species and lawns (Beissinger & Osborne 1982; Emlen 1974; Rudnicky & McDonnell 1989) that are typical of these moderately developed areas. Theory postulates that these birds are pre-adapted as "edge species", (Marzluff 2001), with the ability to do well in edge environments such as around forests and more open areas. These birds reach peak abundances in the suburbs and in Wellington may include native species such as the tui *(Prosthemadera novaeseelandiae)* and introduced birds like the blackbird (*Turdus merula).*

The flora of urban landscapes can be substantial and diverse but exists mostly as remnant fragments in the case of native vegetation, or as cultivated gardens or plots in suburbs and city parks (McKinney 2006). Increasingly planted traffic islands and wooded urban and sub-urban streets provide intermediate habitat. In the building of new cities,

establishment of exotic species occurs in proportion to the degree of disturbance, with alien plants only colonizing up to the border of the altered zone (Rapoport 1993). Invaders and weeds prosper where water is supplemented and weedy species are dispersed by wind, and cultivars by humans. Birds disperse the seeds of invasive shrubs and fruit, with some plants largely depending on birds for dispersal.

Conservation and management

Management of urbanised and urbanizing areas for the purpose of increasing bird biodiversity conservation is complex. It requires understanding of the causative processes in diversity patterning (MacArthur 1972), and of how diversity arises and is maintained in space (Lande 1988). It necessitates design of land-use plans that continue to meet the needs of human settlement while at the same time protecting habitat for the benefit of birds.

There is evidence that native forest birds are now recolonising Wellington and that this is occurring prior to or concurrent with translocations of more rare species to nearby reserve land (Miskelly et al. 2005). For example, the frequency of sightings of unmarked individuals of three species, namely red-crowned parakeet (*Cyanoramphus novaezelandiae*), bellbird (*Anthornis melanura*) and whitehead suggest these birds have established resident populations locally (Miskelly et al. 2005). Two other species, North Island Kaka (*Nestor meridionalis septentrionalis*) and tomtit (*Petroica macrocephalia*) have also been recorded in low numbers (Miskelly et al. 2005). The successful and continuing establishment of these and other rare birds within and around Wellington is a consequence of both extensive ongoing animal pest control and restoration initiatives being undertaken by the Greater Wellington Regional Council, the Wellington City Council, Karori Wildlife Sanctuary Trust and the Department of Conservation.

Study sites and study animals

The New Zealand urban environment and conservation

New Zealand has become a highly urbanised nation with as much as 85 % of its population now living in urban centres and nearly 72 % in the 16 largest urban environments (Boothroyd & Drury 2008). This movement to urban living follows a global trend that anticipates the shift to "megacities" housing in excess of 10 million people (Pearce 2006). In proportion to the area they occupy cities consume vastly greater amounts of resources and expel the larger amount of this as waste (Pearce 2006). New Zealand cities are no exception to this pattern and the focus for management has moved toward making cities more livable and self-sustaining. In urban areas engagement of the community and maintaining community well-being have become pivotal to this goal. For example, surveys suggest that public sentiment continues to place priority on better care of the country's waterways, reducing waste and having clean air (Boothroyd & Drury 2008; Parliamentary Commission for the Environment 2002).

An area of neglect is considered to be land in private ownership (Brakey 2003). The idea promoted here is that urban areas cannot be separate from biodiversity management, and the greening of cities creating connected networks of open space within and around the more densely settled core will contribute to urban biodiversity and make cities more livable. The Wellington City Council Open Network Strategy defines open space as outdoor places of ecological, recreational, landscape and heritage value and has made open spaces an integral part of managing the shape of Wellington (Wellington City Council 1998).

The Wellington urban avian community

The Wellington avian community is described (Table 1.1) and gives details of the species ecology including source of food, habitat, sociality and mating system. The size of the bird in grams (Crowe 2001; Heather & Robertson 1996) is also given.

Table 1.1. Taxonomy, ecology and size (g) of birds comprising the Wellington avian community.

Native species are organised from most common to least common terrestrial birds, then most to least common sea birds. Introduced species are also grouped from more to less common.

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Native species					
Silvereye: Zosteropidae	13	Insects, other invertebrates, fruit and nectar.	Vegetated native habitat – forest, shrubland and mangroves, ground to canopy.	Flocking. Feeds in groups of mixed species.	Territorial in breeding, monogamous.
Tui: Meliphagidae	105	Nectar, honeydew, fruit. Invertebrates.	Mature native dense podocarp-broadleaf forest; in canopy and sub-canopy.	Solitary or pairs.	Territorial all year, monogamous.
Grey warbler: Acanthizidae	6.5	Insects and insect larvae, spiders (gleans).	Vegetated native habitat – forest, forest margins, shrublands, mangroves, all levels.	Small flocks for feeding; often mixed species.	Territorial all year, monogamous.

Table1.1 *continued*

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Fantail: Monarchidae	8	Insects and insect larvae. (Hawks).	Open native forest and scrub – coast to sub-alpine.	Small flocks.	Territorial all year, monogamous.
Bellbird: Meliphagidae	30	Nectar, fruit insects.	Mature native forest, podocarp-hardwood – all levels of canopy.	Solitary or pairs.	Territorial all year, monogamous.
Kingfisher: Alcedinidae	65	Marine and freshwater invertebrates and fish. Terrestrial insects and mice. (Ground feeder).	Native forest – dense under-storey, edge of forest, along watercourses and estuaries. In canopy.	Solitary or pairs.	Monogamous sustained.
Whitehead: Pachycephalida	16	Insects, fruit and seeds (gleans).	Open native forest and dense scrub; grass cover; coast – sub alpine.	Gregarious; small flocks for feeding, larger in winter (mixed).	Mostly monogamous co-operative and territorial in breeding.
Kaka: Psittacidae	500	Native fruit, flowers, seeds, nectar and insects.	Dense native forest – broadleaf and podocarp mix.	Solitary or small group.	Territorial, monogamous.

Table 1.1 *continued*

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Shining cuckoo: Cuculidae	25	Mainly smaller insects.	Dense native forest – beech, broadleaf, podocarp mix.	Solitary or two - some pre-migratory flocks.	Parasitic on greywarbler.
Long-tailed cuckoo: Cuculidae	125	Larger invertebrates, some fruit and berries.	Dense native forest – beech, broadleaf, podocarp mix.	Solitary or small group.	Lek-type (unclear). Parasitic on whitehead.
NZ wood pigeon: Columbidae	650	Native fruit, foliage, flowers and buds.	Native dense forest, canopy & sub canopy.	Solitary or pairs.	Territorial in breeding. Monogamous.
Welcome swallow: Hirundinidae	14	Aerial insects – screen or sally in air. Also gleans foliage	Open grasslands, sedge, and shrub, open forest. Over water.	Solitary or twos; Feeding flocks (+100) April-September.	Monogamous, pair fidelity. Nest in pairs.
New Zealand Pipit: Motacillidae	40	Invertebrates.	Montane, grasslands, sand dunes, braided rivers.	Small flocks (juveniles) – autumn to winter.	Territorial all year. Monogamous.

Table 1.1 *continued*

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Paradise shelduck: Anatidae	1550	Herbivorous – seed heads and grazes crops. Juveniles eat insects.	Hilly country with soft substrata and over water.	Either pairs with territory or communal flocks.	Life-long monogamous . Nest singly, territorial in breeding.
Black-backed gull: Laridae	950	Marine invertebrates and fish. Predator – small mammals. Scavenger.	Coastal and estuarine.	Flocking and gregarious all year, in roosts and feeding.	Monogamous, pair fidelity.
Red-billed gull: Laridae	280	Marine invertebrates also pelagic plankton. Opportunist scavenger.	Coastal and marine.	Flocking; gregarious all year in feeding, roost and flight.	Monogamous Pair fidelity in breeding.
Black shag: Phalacrocoracidae	2200	Mostly fish –trout eels; freshwater crayfish and insects.	Terrestrial wetlands and coastal. Inland waterways.	Solitary. Congregate at food supply – large flocks.	Sustained monogamous territorial in breeding. Colonial or single nests.
Little black shag: Phalacrocoracidae	800	Fish – smelt, carp, perch, small crustaceans.	Vegetated wetlands, sheltered coastal.	Solitary or gregarious; congregate for feeding, breeding. Communal roosts.	Sustained monogamous Mostly colonial nesting – mixed species.

Table 1.1 *continued*

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Little shag: Phalacrocoracidae	700	Freshwater crayfish, other crustaceans, some fish.	Terrestrial wetlands, sheltered coastal and inland waterways.	Solitary, congregate for nesting and feeding.	Sustained monogamous. Colonial nesting – in mixed species.
Variable oystercatcher: Haematopodidae	725	Molluscs, crabs and worms, some small fish. Mobile in foraging.	Coastal and offshore, sand spits and estuarine.	Gregarious outside breeding. Winter flocks in feeding.	Territorial sustained monogamous.
Introduced species					
House sparrow: Ploceidae	30	Mostly seeds of cereals, grass and weeds; Insects, fruit, and berries.	Open – woodlands or shrub, not dense. Now commensal with human.	Communal; gregarious – discrete colonies, large feeding and roosting flocks.	Territorial in breeding. Monogamous.
Starling: Sturnidae	85	Spring – insects & their larvae. Soft fruits, seeds, cereals. Opportunist.	Open forests, woodland margins, rocky coastline, and grasslands. Mobile in foraging.	Gregarious all year. Feeding and roosting flocks.	Monogamous and polygynous.

Table 1.1 *continued*

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Feral pigeon: Columbidae	400	Mostly seeds of cereals, legumes and weeds, some foliage, buds and insects.	Coastal rock faces – linked with nest sites. Also on margins behind cliffs.	Gregarious in roosting feeding, flying and loafing.	Mostly colonial; monogamous.
Blackbird: Muscicapidae	90	Insects, earthworms, fruit.	Woodlands – mix forest, rich soils, (ground layer).	Solitary, but aggregate at food supply.	Territorial all year, Monogamous, pair fidelity.
Chaffinch: Fringillidae	22	Mainly seeds and plant material. Invertebrates for Young.	Deciduous & coniferous woods/ forests. Non breeding – in more open.	Gregarious outside breeding – flocks for feeding, roosting (+1000).	Territorial, monogamous.
Greenfinch: Fringillidae (Carduelinae)	28	Large hard seeds (Cruciferae), cereals and herbs. Few invertebrates	Densely leafed trees; woodland edge, scrub, grasslands with trees.	Gregarious outside breeding – large flocks in winter.	Mainly monogamous, 20 % polygynous.
Goldfinch: Fringillidae (Carduelinae)	16	Soft small seeds (Compositae). In breeding some invertebrates. Very mobile and seasonal in feeding.	Breeding- streamside, fens, woodlands, fringe woodlands & scrub. Non breeding – grasslands.	Gregarious outside breeding, communal roosts. Flock size dependent on food supply.	Monogamous territorial in breeding.

Table 1.1 *continued*

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Mallard: Anatidae	1200	Omnivorous and opportunist. Aquatic seeds, plants and some insects.	Estuarine and freshwater, shallow marine.	Gregarious. Travel in flocks if migratory.	Communal, pairs and trios.
Dunnock: Prunellidae	21	Insects, and seeds in winter.	Temperate scrub and stunted coniferous, ground layer.	Solitary; aggregate at food supply.	Territorial, mostly monogamous.
Song thrush: Muscicapidae	70	Invertebrates, and their larvae, fruit.	Mix – grassland and woodlands in lowlands; mostly ground layer.	Solitary or small feeding or roosting flocks.	Territorial, monogamous.
Australian magpie: Cracticidae	350	Mainly invertebrates. Some seed, carrion and small mammals.	Open country and forest.	Solitary or pairs.	Territorial all year.
Redpoll: Fringillidae (Carduelinae)	12	Very small seeds (Betula, Compositae), and invertebrates when breeding.	From no trees to shrub land and stunted forest. Open scrub woodland and edge.	Gregarious outside breeding. Winter flocking, some communal roosting.	Monogamous. Pair fidelity. Some nest in groups.

Table 1.1 *continued*

Taxonomy: Species and family	Average size of bird (g)	Food source	Habitat	Sociality	Mating system
Eastern rosella: Psittacidae	110	Open woodland, lightly wooded grasslands.	Seeds of grasses, shrubs and trees; fruit, buds, flowers, nectar, insects and larvae.	Gregarious, flock after breeding; roost in pairs.	Monogamous sustained.
Yellowhammer: Emberizidae	27	Seeds, mainly grasses; some insects.	Open lowlands or hilly country; edge of open area of forest and scrub.	Aggregate at feeding sites, mostly winter – mixed.	Territorial monogamous (some polygyny).
Rook: Corvidae	400	Invertebrates – mainly beetles, cereal grains, small vertebrates.	Montane, edge of forest or woodlands, groves and riverain fronting grasslands.	Gregarious outside breeding for feeding, roosting and migration.	Monogamous sustained; colonial nesting.

Source: Handbook of Australian, New Zealand and Antarctic birds, volumes 1, (part A & part B), 3, 4, 5, 6, 7 (part A & part B) (Marchant & Higgins 1990a; Marchant & Higgins 1990b; Higgins & Davies 1996; Higgins 1999; Higgins & Peters 2001; Higgins & Peters 2002; Higgins et al. 2006a; Higgins et al. 2006b).

Handbook of the birds of Europe, the Middle East and North Africa. The birds of the Western Paleartic. Volumes V, VIII and IX (Cramp et al. 1988; Cramp et al. 1994; Cramp et al.1994).

Which New Zealand Bird? (Crowe 2001)

The field guide to the birds of New Zealand (Heather & Robertson 1996).

General methods used to assess biodiversity in the urban environment

Two types of error, sampling bias and sampling variability, may be associated with index counts like the FMBC. Bias reduces the accuracy of the data in that the counts can either overestimate (positive bias) or underestimate (negative bias) the population (Thompson 2002). Sampling variability decreases the precision of the data and occurs as an effect of the repeated sampling itself (Thompson 2002). Sampling variability is a concern because variation in the number of birds observed between counts may obscure real changes in bird numbers. Therefore, standardising conditions such as time of day, recording of environmental and weather conditions and ensuring that the sample size is large enough to answer the questions asked will help to reduce variability and make the study more valid.

Point counts (where the observer is sedentary at one place), and strip-transects (where the observer walks along a strip) are among the most frequently used techniques for monitoring terrestrial birds both in New Zealand and internationally. A review of landbird studies published in the ten years between 1989-1998 in nine major journals and one symposium indicated a heavy dependence on use of these index counts (Rosenstock et al. 2002).

How the five-minute bird count is used

Bird population monitoring programmes vary in how they conduct bird counts. The Breeding Bird Survey (BBS), for example, is run in Britain and variants of it are used by 18 other European countries (Spurr 2005). Five-minute point-based distance counts are used in France that specify the area of the sampling site and the distance bands used around each point, (<25m, 25-100-m, and >100-m) (Spurr 2005). In the United States the BBS uses three-minute counts of all birds seen and heard within a 400m radius around the

point. The BBS programmes monitor the trends in terrestrial bird populations and all results are published on-line (British Trust for Ornithology 2008). Still other research (Bolger et al 1997; Melles et al. 2003) used point counts to monitor either the abundance of breeding birds or to assess urban bird biodiversity in urbanising landscapes.

In New Zealand the five-minute bird count (FMBC) was adopted as the standard method of avian community monitoring, particularly in forests (Dawson & Bull 1975). It has persisted as the most widely used means of determining the status and trend of bird populations within forested populations (Hartley & Greene 2008). The Ministry for the Environment (MfE) has the task of developing tools for national biodiversity monitoring and reporting. For birds, it has recommended use of five-minute point counts (Froude 2003). In 2003 the Department of Conservation (DOC) initiated the development of a national database of FMBC collections for monitoring trends in common land and seabird populations. The project included the collation and entry of historically significant datasets as well as entry of current FMBC data (Hartley 2007). The method has since been integrated into the DOC toolbox of standard monitoring techniques for use within DOC (Hartley 2007). Finally, regional and city councils have responsibility for monitoring biodiversity in their districts. Hamilton City Council, for example, uses the FMBC protocol in green and residential areas of the city, as well as completing transect counts of birds in native vegetation in November and December (Spurr 2005).

Evaluation of FMBC as a monitoring technique – advantages and limitations

The FMBC is an index measure only because it detects just a proportion of all birds present while some remain hidden in surrounding vegetation (Hartley & Greene 2008). It is attractive because it is cheap and requires minimal effort while still allowing large numbers of controlled counts to be conducted. The method is suited for use in densely

vegetated habitat and, because the observer is standing still, for detecting birds that are more inconspicuous or cryptic (Hartley & Greene 2008). Its main application is to provide information on the relative abundance of a population of individuals for comparison over time or at different sites.

Detractors of the technique argue that the reliability of point counts rests on the assumption that the counts relate consistently and positively with actual bird density (Rosenstock et al. 2002). Three classes of variables (Rosenstock et al. 2002) influence the reliability of this outcome: (1) the ability of the observer to correctly identify birds (by sight or sound), (2) the environmental conditions and (3) the different characteristics of the birds. (1) The ability of the observer is influenced by many factors but most importantly by level of training/experience, hearing acuity and eyesight. (2) Environmental conditions, including weather, time of day, season, topography and vegetation. These affect bird behaviour and compromise efficiency of the observer, and (3) the characteristics of the birds that make them more or less conspicuous. For example age, sex, flushing or flight behaviour and loudness of call will all influence detection (Rosenstock et al. 2002). The validity of indices thus depends on standardisation or elimination of these variables (Spurr & Powlesland 2000). Lastly, the technique is less suitable for the counting of rare or abundant flocking species as the high frequency of counts in which none are seen, or more than can be counted are seen, causes a high variability between counts (Hartley & Greene 2008).

How strip-transects are used

Bird population monitoring in New Zealand has also used strip-transect counts. Methods vary with the length of the transect and the distance bands selected, but all involve

walking slowly along the transect while counting birds seen within a set distance either side of the transect (Spurr 2005).

Study objectives

This study investigates and describes avian community composition amongst habitats within a variably urbanised landscape and, at a finer scale, amongst habitat patches along these strips. Patterns were studied over the period of one year in order to determine the impact of season and time of day on the distribution, richness and abundance of this community. In particular I seek to understand if the fundamental ecological relationships of heterogeneity and diversity in wild landscapes can also be applied in urban areas. In chapter two I set out to test the hypotheses that species richness decreases and abundance increases with proportion of built landscape. In order to do this I monitored occurrence and abundance of all species of birds I saw or heard along strip-transect segments within classified landscapes. In chapter three I investigate the hypotheses that a positive relationship exists between habitat diversity and species richness, and that species richness increases with average patch size. I also predict that the number, the largest size and total area of a species favoured habitat will relate positively with abundance. Chapters two and three are written as separate manuscripts for publication so some repetition of general information occurs. A synopsis of general findings and recommendations for management are detailed in Chapter four.

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Chapter 2: Avian biodiversity and abundance in a variably urbanised landscape

Abstract: Avian assemblages fluctuate across the urban landscape at different scales of space and time and in response to a variety of factors. Community composition and abundance in landscape is also influenced by a species ecology. I studied the spatial and temporal distribution of the avian community in Wellington City, New Zealand, at monthly intervals between March 2007 and February 2008 to assess the effect of urbanisation on species richness and abundance of birds. My study was located within a 5 km radius of Wellington City's central business district (41° 16' S, 174° 46' E). I used six strip-transects divided into 400m length segments that traversed through high to lower density residential suburbs and green space inter-digitised with built habitat. I recorded avian species type and abundance in each segment along these strips during the morning and evening and recorded a total of 35 species involving 10966 individuals. Results indicated that landscape classification modified avian biodiversity with 50% more species recorded in green landscapes than at low storey commercial sites. The highest number of species (S) was recorded in green landscapes (S = 15.9) and the lowest in wharf littoral (S = 7.5) and low commercial sites (S = 6.7). The diversity of landscape types within a segment did not influence biodiversity. I found that although total species abundance did not change across landscape, each species historical ecology significantly modified where it occurred and its abundance within landscape. My results indicated an effect of both season and time of day on species richness and abundance. Numbers of species in the morning were 30% lower in autumn than counts for other seasons. Food diversity particularly influenced the species abundance.

Introduction

At the level of the individual a species interacts with its environment both in space and time (Brown et al. 1995). The avian community is not a stable entity but also fluctuates within the landscape at different scales of space and time and in response to a variety of factors (Maron et al. 2005). Temporal scales include time of year or season and the associated factors are changes in climate and resources, and life history, including breeding, migration and recruitment (Blake et al. 1994). The ecology of the species (Table 1.1), particularly its feeding and nesting guild, also influence variability in the local community through its effects on breeding success and mortality of juveniles or adults (Maron et al. 2005). In space the organism's response may be at the broader scale of landscape, or at the level of habitat patch and grain that is within patch selection (Hostetler 2001; Kotliar & Wiens 1990). At this smaller scale the organism is responding to fine patch structure for the purpose of foraging. Factors that elicit response include food shelter or microclimate. For example, for house sparrows, the warmer surface of a stretch of sealed road or rooftop may define a patch.

Most terrestrial birds in New Zealand do not migrate nationally and only the two species of cuckoo (Cuculidae) migrate from the country in winter (Heather & Robertson 1996). However, there is considerable localised movement of flocking gregarious species like silvereye (*Zosterops lateralis*: Zosteropidae), finches (Fringillidae) and house sparrow (*Passer domesticus*: Ploceidae) that congregate during the winter and disperse in summer (Heather & Robertson 1996; Troup 2008). Movements of gregarious species are both daily and seasonal, between roosting and feeding sites. Solitary, territorial birds like the native tui (*Prosthemadera novaeseelandiae*: Meliphagidae) will also become partially nomadic outside the breeding season in search of food (Heather & Robertson 1996).

Some seabirds and freshwater birds seen in Wellington however do move nationally. For example the native South Island pied oystercatcher (*Haematopus ostralegus*: Haematopodidae) migrate north after breeding, while black-billed gulls (*Larus bulleri*: Laridae) and some inland breeding kingfisher (*Todiramphus sanctus*: Halcyonidae) winter at coastal sites (Troup 2008). Black-backed gulls (*Larus dominicanus*: Laridae) are largely sedentary but red-billed gulls (*Larus novaehollandiae*: Laridae) complete regular seasonal journeys of hundreds of kilometres between breeding and traditional wintering sites (Heather & Robertson 1996). Shags disperse widely after breeding in autumn with considerable local movement between concentrated food sources and roosting sites and fledlings, particularly of black shag (*Phalacrocorax carbo*: Phalacrocoracidae) occasionally migrate nationally (Heather & Robertson 1996).

In unmodified ecosystems, spatial fluctuations in richness of species and abundance of individual species occurs to the extent that local sites meet species niche requirements (Brown et al. 1995), particularly food supply and water, and nesting and roosting opportunities. Brown et al. (1995) suggested a niche-based hypothesis to explain a common spatial pattern in avian abundance: that most species are rare at most sites but are abundant in a few sites called “hot spots”. Both the number of habitats and their configuration in space as well as climate and predator threat are significant determinants of the pattern (Blake et al. 1994). The ecology of cities, however, may be different because they exist in a highly modified and dynamic state. Their landscapes do not easily fit the simplistic concept of habitat/non habitat (Blair 2004). Urban areas create a complex collage of landscapes that vary from virtually unmodified to highly developed commercial districts (Blair 2004) that exist spatially along a gradient of disturbance. This high degree of environmental variation has profound consequences for species abundance, richness and composition in cities.

The aim of this chapter is to investigate how species richness and abundance of birds changes across the urban environment depending on the degree of development and to measure this variation at daily and seasonal temporal scales. My hypothesis is that species richness decreases as proportion of built landscape, and therefore degree of modification and disturbance, increases. I expect species richness and abundance to be greater in spring and summer because some birds migrate into Wellington at this time and because of spring breeding. If migratory birds are discounted I expect there will be no change in species numbers.

Methods

Location and environment of Wellington City

Wellington is situated at the southern tip of North Island, New Zealand, at latitude of about 41.25ºS (Figure 2.1). All areas were developed from the mid 19th century and more so after Wellington became New Zealand's capital city in 1865 (Wellington City Council 2008b). Wellington is New Zealand's third most populous city with a greater urban area including the cities of Lower Hutt, Upper Hutt, Porirua and the Kapiti Coast District (Greater Wellington Regional Council 2008). The city is now more densely populated than most other urban areas in New Zealand due to the limited amount of low slope building space between the harbour and surrounding steep hill country. Wellington's 2006 population was 179,466 in 28,990 hectares or a population density of 619 individuals per km^2 (Wellington City Council 2008a). Wellington therefore is just classified as 'urban' by international guidelines (i.e. 620 individuals and above per km^2) (Bourne & Simmons 1982).

Wellington region has a diverse range of landscapes including up to 500 square kilometres of regional parks and forests and 102 parks or recreation areas within the city. Most of the city's suburbs lie within three kilometres of the coastline. (Wellington City Council 2008a). Wellington has a mild temperate but windy climate without marked seasonality. Average temperatures vary between 9º C (July – midwinter) and 17º C (February – late summer). Average annual rainfall is 1270mm with 2025 average annual sunshine hours. The New Zealand Metservice (Court 2008) recorded an average mean annual wind speed of 22km/hr and an average of 22 days per year with mean wind speeds of over 63km/hr or 40 knots (gale force).

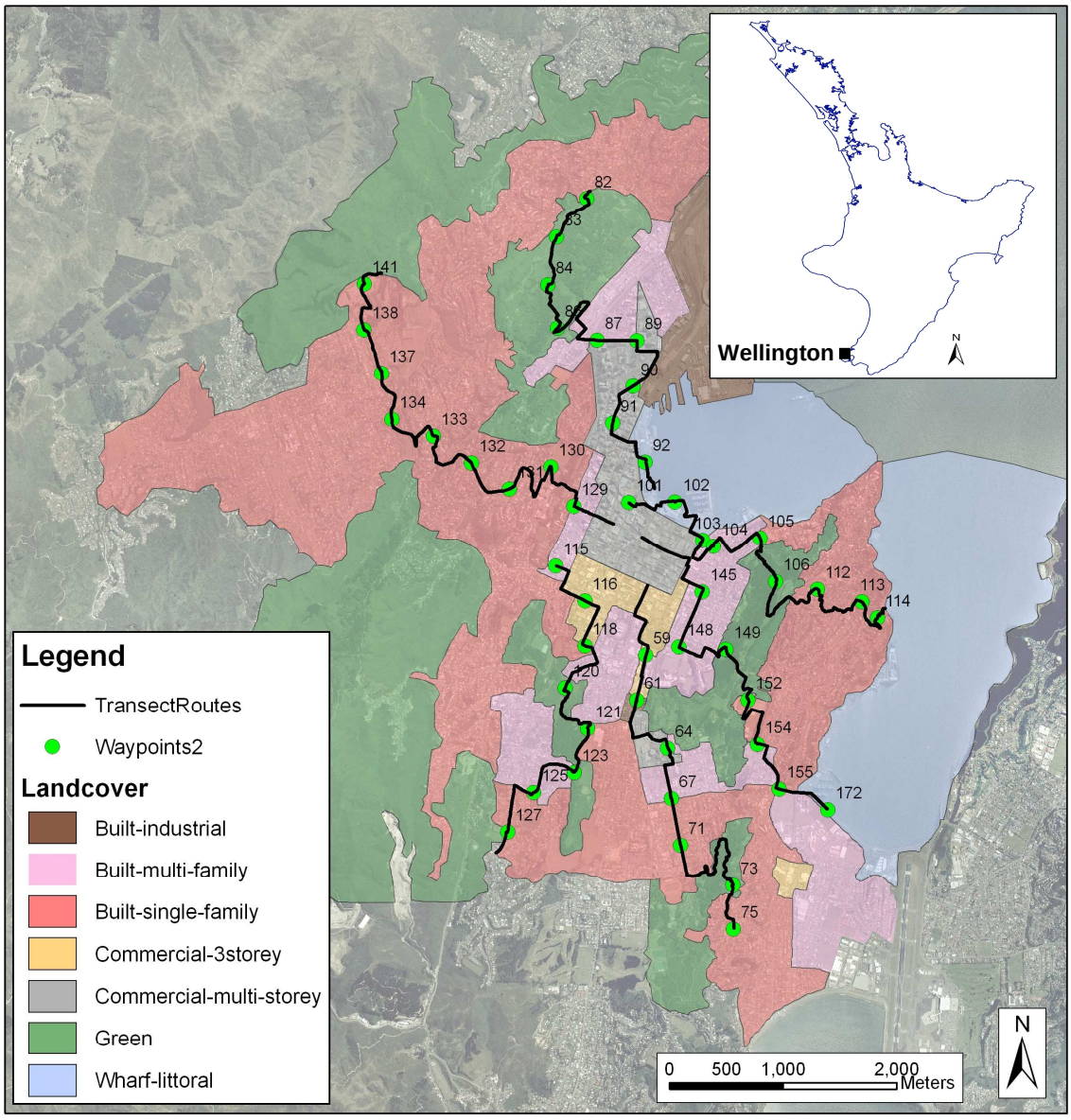

Figure 2.1 Aerial map of central Wellington City showing study area, landscape types, strip-transect routes and five-minute bird count stations (numbered circles). Inset: map of North Island, New Zealand showing the location of Wellington City. (Source: original aerial view obtained from the LINZ website).

Study area and design

The study occurred within a 5-km radius of Wellington City's central business district (CBD) (41° 16' S, 174° 46' E) (Figure 2.1). I selected sampling routes for the strip-transects to reflect typical forms of development in the urban-suburban landscape of Wellington City. Strip-transects radiated out from the city's CBD through high to lower density residential suburbs and green space inter-digitated with built habitat. All routes included pronounced gradients of urbanisation from recreational reserves and parks, suburban residential, inner city residential, light industry, commercial and central business areas (see Table 2.1 for a description of the sampling routes).

Strip-transect segments were divided into 400m linear intervals along the sampling route. There were from seven to nine segments along each strip-transect. Each strip-transect was conducted monthly at three times of the day – morning (7.00 – 10.30am), midday (12.00 – 3.00pm) and evening (5.00 – 8.00pm). The months were grouped into seasons. Autumn extended from March to May, winter from June to August, spring from September to November and summer from December to February. Winter periods began a half-hour later in the morning and an hour and half earlier in the evening to allow for the later time of sunrise and earlier sunset. The direction the strip-transect was conducted was reversed in alternate months. (see Table 2.2 for monthly sampling schedule).

I walked slowly along each strip-transect and recorded all individual birds and groups of birds I saw or heard, their species, and the number in each group. I placed the groups into perpendicular distance categories away from the strip-transect. The distance categories were 0-5, 5-20, 20-40, 40-100, 100-200, and greater than 200 metres. The time I took to walk each strip-transect segment varied from 25 to 40 minutes.

Table 2.1. Description of the six strip-transects (A to F) walked through Wellington City.

Sampling route	Description of sampling route
A	Frank Kitts Park (Queens Wharf) ▫ Lambton Quay ▫ Hill Street Tinakori Road ▫ Grant Road ▫ Town Belt ▫ Weld Street (Wadestown).
B	Kio Road (Evans Bay Parade) ▫ Ariki Road ▫ Alexandra Road ▫ Town Belt ▫ Mt. Victoria ▫ Kent Terrace ▫ Cable Street ▫ Wakefield Street (Wellington).
C	Cobham Street (Kilbirnie) ▫ Moxham Street ▫ Hataitai Park ▫ Alexandra Park ▫ Brougham Street (Mt. Victoria) ▫ Elizabeth Street ▫ Kent Terrace ▫ Courtney Place (Wellington central).
D	Sutherland Road (Melrose) ▫ Truby King Park and Town Belt ▫ Daniel Street (Newtown) ▫ Wellington Hospital ▫ Ridderford Street ▫ Adelaide Road ▫ Basin Reserve ▫ Tory Street (Wellington central).
E	Wentworth Street (Mornington) ▫ Mills Road ▫ Whaui Street ▫ Prince of Wales Park (Town Belt) ▫ Rolleston Street ▫ Hopper Street ▫ Webb Street ▫ Abel Smith Street (Te Aro).
F	Karori Cemetery ▫ Chaytor Street ▫ Northland Road ▫ Upland Road ▫ Kelburn Parade ▫ Victoria, University of Wellington campus ▫ The Terrace ▫ Dixon Street (Wellington central).

Table 2.2. Monthly sampling schedule for sampling strip-transects A to F from March 2007 through to February 2008, during morning (M), afternoon (A), and evening (E) time periods. March to May = autumn, June to August = winter, September to November = spring, and December to February = summer. After exploratory analyses for the first 6-months data, afternoon sampling was discontinued.

Route	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb
A	E	M	A	E	M	-	E	M	-	E	M	-
B	E	M	A	E	M	-	E	M	-	E	M	-
C	A	E	M	A	E	M	-	E	M	-	E	M
D	M	A	E	M	A	E	M	-	E	M	-	E
E	A	E	M	A	E	M	-	E	M	-	E	M
F	M	A	E	M	A	E	M	-	E	M	-	E

Analysis on ArcGIS

A geo-referenced aerial map of Wellington (Figure 2.1) at a resolution of 1:2,500m (NZTM2000), (Land Information New Zealand 2007), was digitised to categorise it into landscape types. I defined landscape types by the proportion that each contained vegetation cover and the size and density of human-made structures (i.e. buildings and roads) (Clergeau et al. 2001) (Table 2.3). The 400m strip-transect segments were drawn on the map for each of the sampling routes and surrounded by a 200m zone. I considered 200m either side of the strip-transect as the area that the community of birds were responding to at the coarser scale of landscape (Figure.2.2). The diversity of landscapes within each of the strip-transect segments were counted and the percentage area covered by each landscape type measured. The dominant landscape was the landscape that had the highest percentage ground cover in each segment. The industrial landscape was not dominant in any segment.

Species Selection

I selected 12 avian species to study across the seasons within the six dominant landscape types in order to detect and interpret patterns in their abundance. The first six species were the five most common birds, and red-billed gull. The second set, my focal species, included those birds that I expected to show selective occupancy of landscape type because of the presence or absence of preferred habitat and food. I selected four native forest species, silvereye, tui, grey warbler and fantail, and two introduced woodland species, greenfinch and goldfinch within three feeding guilds: granivores, nectivores and insectivores. I conducted preliminary analyses of the data over the initial six-month period using only the six most common species. These included house sparrow, starling, black-backed gull, feral pigeon, blackbird and silvereye.

Table 2.3. Nomenclature and definitions of the landscape types used to describe land cover in the strip-transects segments. Landscapes were classified by the degree to which ground cover consisted of vegetation or human-made structures.

Landscape type	Description of landscape
1. Green	Un-built open reserve land comprised mainly of trees that were mix of exotic and native species including regenerating original vegetation.
2. Residential single-family detached	Single or double storied individual dwellings with large plots and gardens including tree-lined streets, parks, schools and sports fields.
3. Residential multi-family attached	Multi-storey (more than two) apartments with small or no gardens and few or no trees-lined streets.
4. Wharf-littoral	Predominantly wharf frontage and includes beaches and walkways with single or two storey commercial buildings and restaurants.
5. Commercial 1–3 storey	Includes supermarkets and shops, and falls outside the CBD.
6. Light industrial	Includes port, industry and light manufacturing businesses with buildings of one to two storeys.
7. Commercial multi storey	Includes buildings of more than three storeys in the central business district (CBD) such as office blocks, shopping malls, hotels and hospitals.

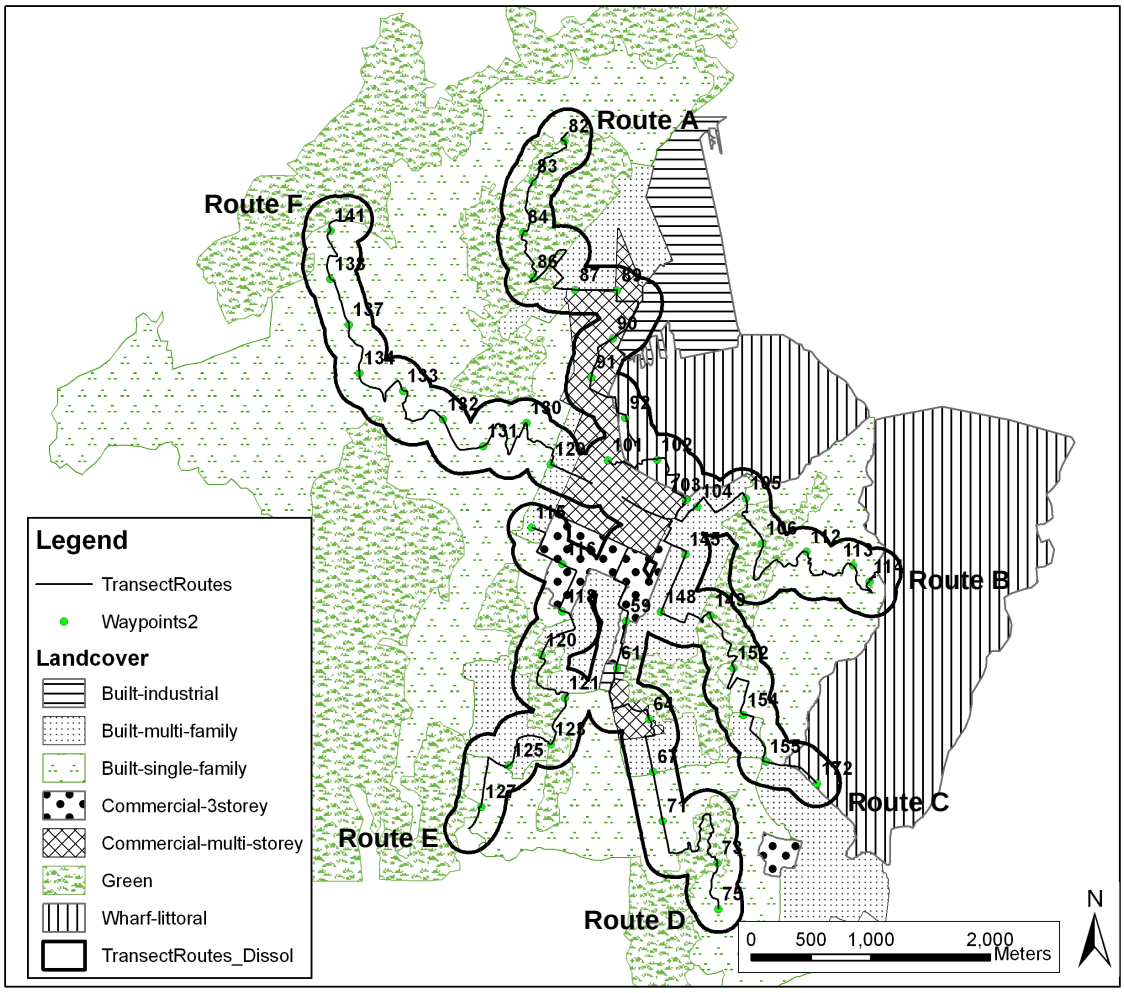

Figure 2.2. Map of landscape types showing strip-transects and the 200 metre area around the strips that was sampled. The five-minute bird count points are numbered along the strip-transects. Landscape types are shown in the background. Routes A to F are described in table 2.1.

Statistical Analysis

Data were analysed using the (1) General Linear Modelling (GLM) univariate procedure for ANOVA and (2) regression analysis on the SPSS statistical programme. For the first six months data that was recorded during the morning, midday and evening periods, univariate ANOVA analysis was used to test for significance of the relationship between season and time of day with (i) species richness, and (ii) abundance of individuals. For the main data set univariate ANOVA analysis tested significance of relationships between species richness and (i) landscape types, (ii) season and time of day and (iii) to assess the accuracy of the model of a species ecology accounting for occurrence of abundance of individuals in landscape and across season and time of day. Regression analysis was used to test the relationship between landscape diversity and species richness.

The landscape richness and species richness across season and time of day, as well as the landscape species ecology data were tested for normality using either the Kolmogorov-Smirnov exploratory analysis or Levene's test of equality of error variance. The correlation coefficient r^2 gave a measure of how precisely the data fitted the models used while the measure Partial Eta^2 was used to explain the ratio of variance accounted for by an effect, and that effect plus its associated error variance (Brown 2008). Statistical significance was assumed at $p < 0.05$ and alpha values <0.1 were examined as possibly indicating a weak trend.

Results

Early afternoon data

Afternoon sampling was discontinued after August 2007 because preliminary analyses of the data for the six most common species for the initial 6-month period indicated that afternoon counts provided no information not already gathered during morning and evening sampling. Counts of species richness were depressed during the afternoon when compared with the number detected during morning and evening periods (Figure 2.3). Average abundance in autumn was equal to or lower than morning and evening periods, with the exception for feral pigeon and house sparrow. In winter only starling and feral pigeon showed higher counts for the afternoon period (Figure 2.4). For these early data there is a significant effect of time of day ($F_{2,30} = 5.972$, $P = 0.007$), but no effect of season on the numbers of species ($F_{1,30} = 1.634$, $P = 0.211$) and no significant interaction between the two ($F_{2,30} = 0.818$, $P = 0.451$). From September to February the afternoon period was omitted (see Table 2.2).

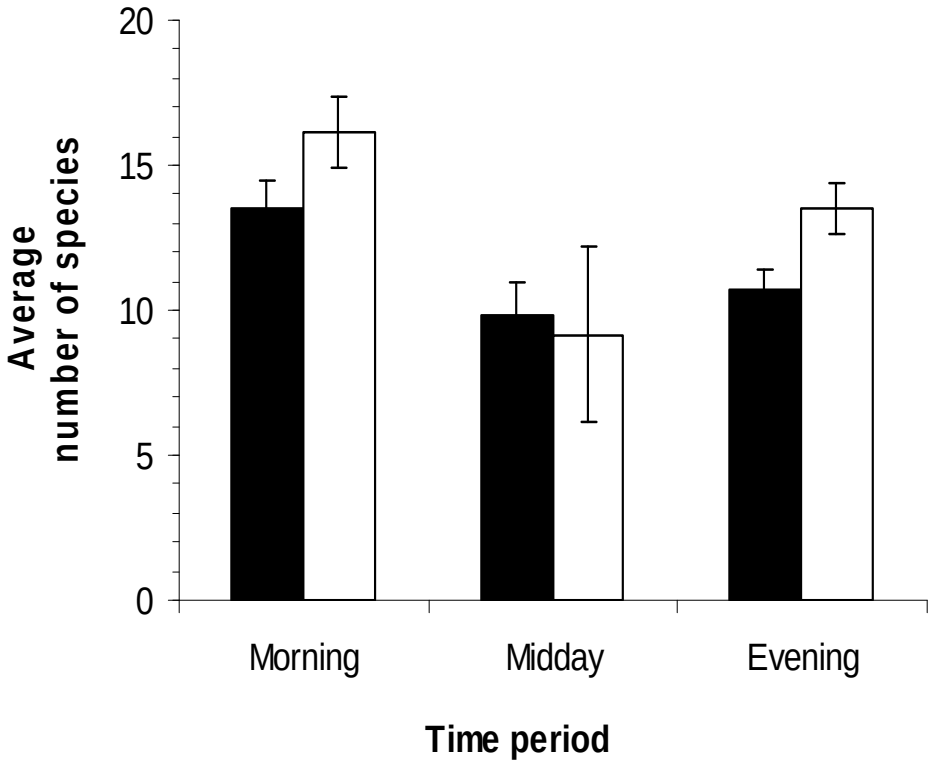

Figure 2.3. Average (± 1S.E.) species richness in the six strip-transects during the morning, midday and evening periods over the 6-month period from March to August 2007. Midday counts for species richness over autumn (■) and winter (□) were significantly lower than the morning period.

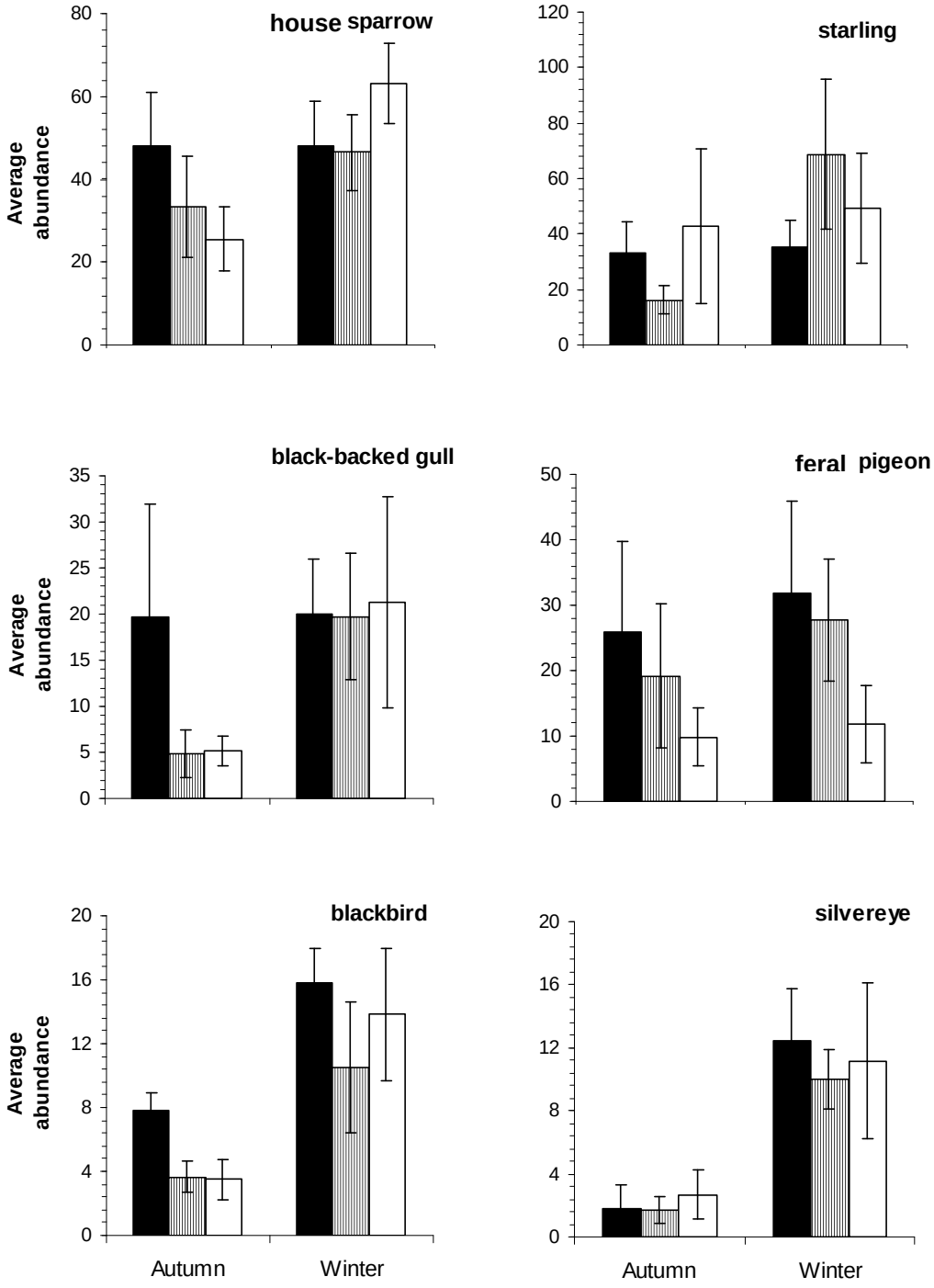

Figure 2.4. Average (± 1S.E.) abundance (mean number of individuals seen or heard per strip segment, n = 3 per season), for the six most common species along the six transect strips in Wellington, during the morning (■), afternoon (‖) and evening (□) periods over the 6 month period from March 2007.

Species occurrence and abundance

Thirty-five bird species and 10966 individuals were recorded over 12 months. Species occupancy of strip-transect segments showed a positive exponential scatter relationship (Figure 2.5). Sparrows were the most abundant and widespread species with 3116 individuals counted and occurring in 49 of 51 strip-transect segments. After sparrows the three most common species were starling (*Sturnus vulgaris*: Sturnidae), black-backed gull (*Larus dominicanus*: Laridae) and feral pigeon (*Columba livia*: Columbidae). The most abundant native terrestrial birds counted were silvereye, followed by tui and grey warbler (*Geryone igata*: Acanthizidae). Tui was most widespread across urban Wellington being present in 78% of strip-transect segments. Grey warbler, although recorded in low numbers occupied 51% of segments. Blackbird (*Turdus merula*:Muscicapidae) and chaffinch, both introduced ground feeding species, were abundant across most strip-transect segments; blackbird totaled 781 individuals in 96% of segments across Wellington. Black-backed gulls dominated all seabirds counted; 1075 individuals in 84% of strip-transect segments. Red-billed gulls tallied at 566 in 41% of segments.

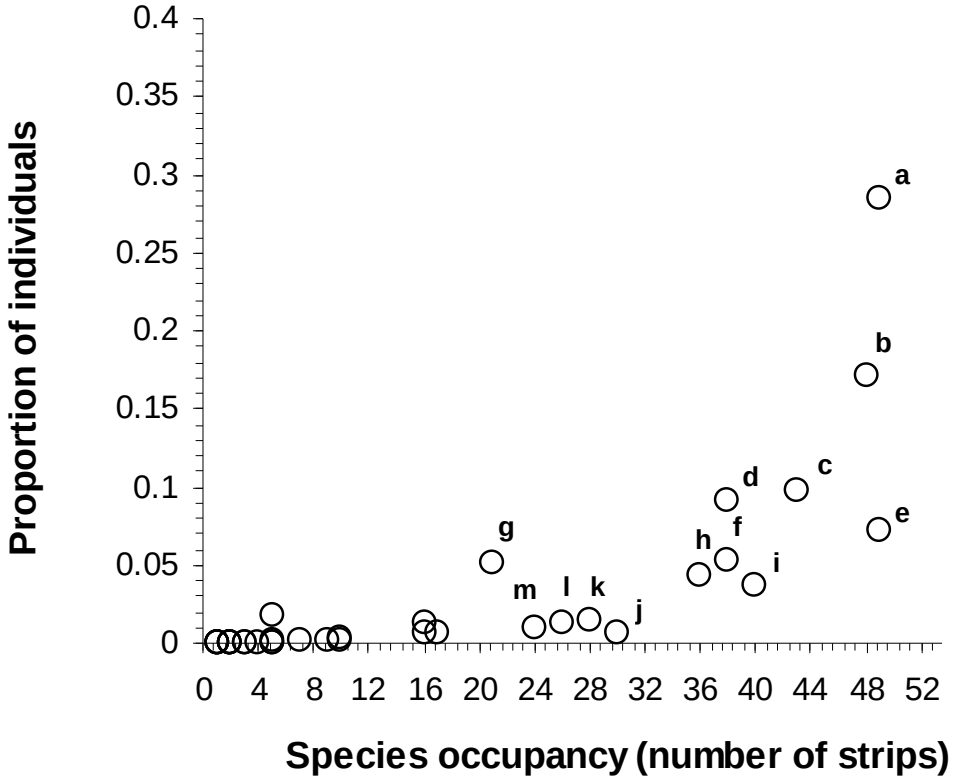

Figure 2.5. Number of strip-transect segments (N=51) occupied by different bird species as a proportion of the total number of individuals counted. The nine most common and widespread species were (a) house sparrow, (b) starling, (c) black-backed gull (*Larus dominicanus*: Laridae), (d) feral pigeon, (e) blackbird (*Turdus merula*), (f) silvereye (*Zosterops lateralis*), (g) red-billed gull, (h) chaffinch and (i) tui. The next most widespread species included (j) song thrush, (k) greenfinch, (l) grey warbler and (m) dunnock. (See Appendix 1 for raw data used to construct this graph).

Spatial distribution and abundance of species

There was a significant difference in species richness (S) across landscape types ($F_{5,45}$ = 7.95, P = 0.001). Average species richness was highest in green landscapes (S = 15.9) and less in stages to the wharf-littoral (S = 7.5) and commercial landscapes (S = 6.7) (Figure 2.6). A count of different landscape types within the strip-transect segments ranged from one to five with the majority of segments having two or three different types of landscapes. Species richness was not different among segments although the relationship was approaching significance ($F_{1, 49}$ = 3.346, P = 0.073, R^2 = 0.005) (Figure 2.7).

The least variable counts and lowest numbers of house sparrow and starling were observed in green followed by residential-detached landscapes (Figure 2.8). Higher but more variable numbers of both species were counted at commercial sites. A similar pattern occurred for gulls – only occasional observation of these species was recorded in green landscapes that were largely avoided by gulls, while low numbers were counted in residential-detached landscapes. Aggregations of feral pigeon were also uncommon in green landscapes but occurred in highest numbers in commercial landscapes (Figure 2.8).

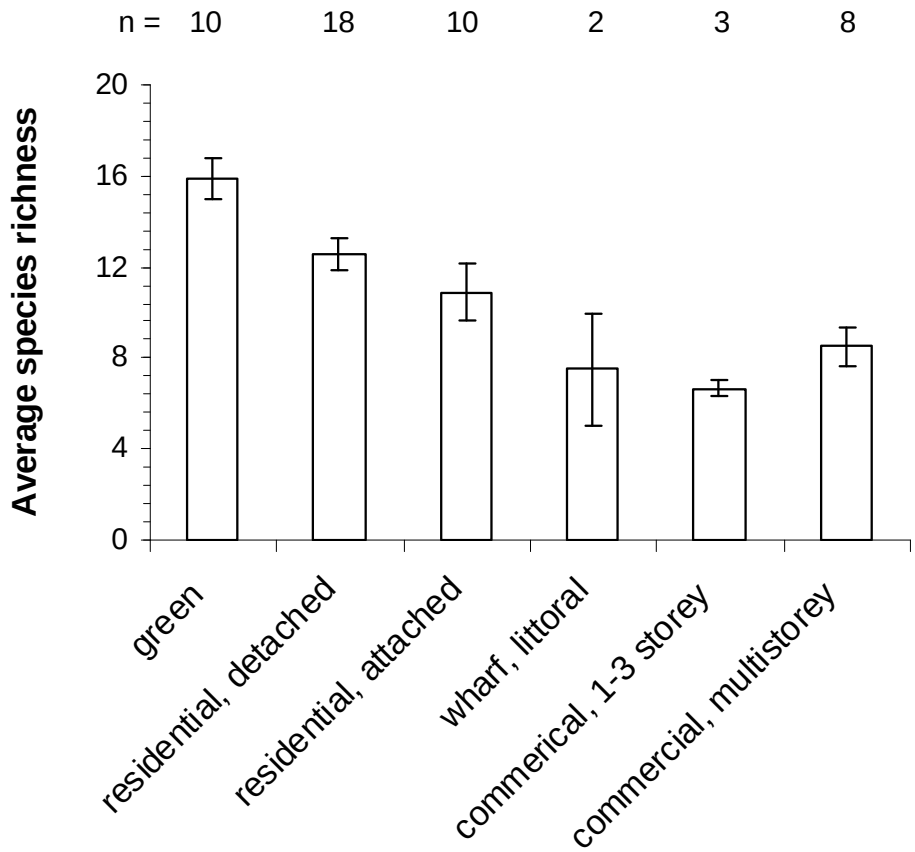

Figure 2.6. Average (± 1S.E.) species richness in 6 of the 7 landscape types across the 51 strip-transect segments in Wellington City. Landscapes are ranked from green to more built types, n indicates the number of strip-transect segments dominated by each landscape type.

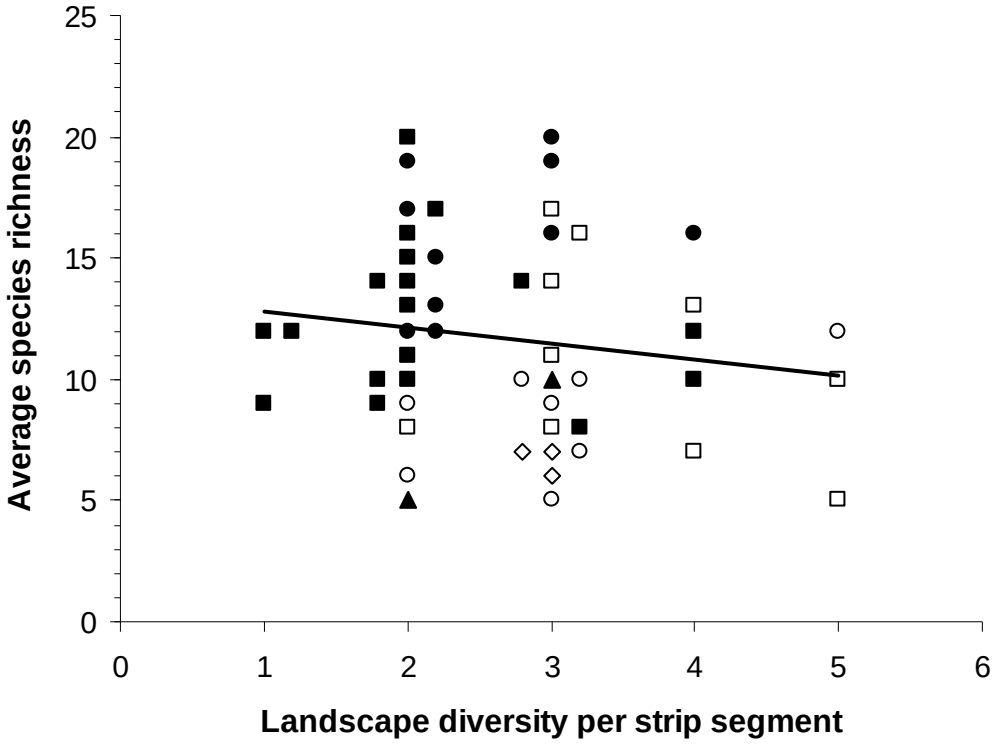

Figure 2.7. The relationship between average species richness and diversity of landscapes per strip-transect segment in Wellington City. Segments with overlapping marks of landscape diversity and species richness were separated for display purposes. Codes for landscape types are green (●), residential, detached (■), residential, attached (□), wharf, littoral (▲), commercial, 1-3 storey (◊), commercial, multistory (○).

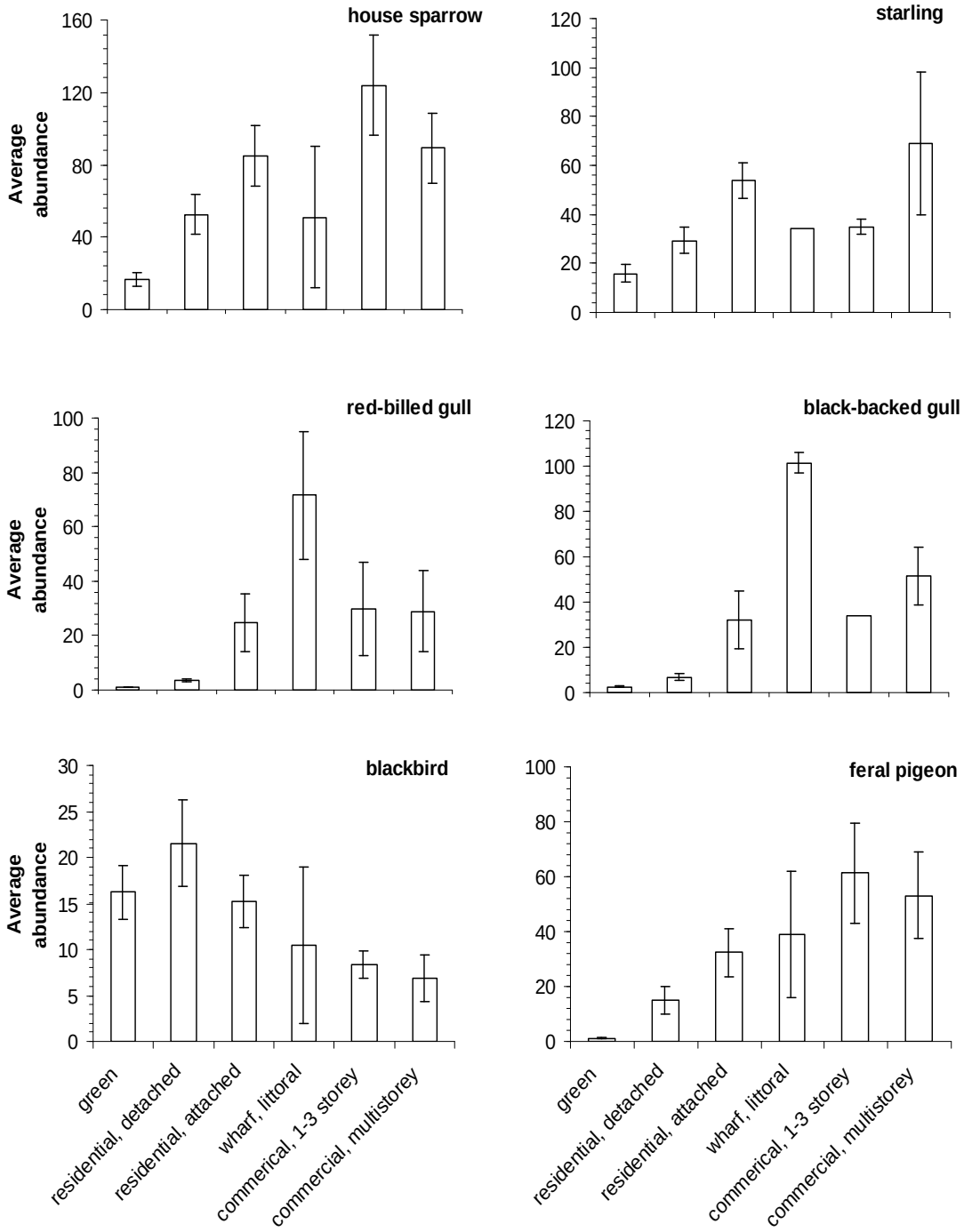

Figure 2.8. Average (± 1S.E.) abundance per strip-transect segment, of individuals seen or heard along the six strip-transects conducted over eight walks, for six common species in the dominant landscape types.

Blackbirds were abundant in all landscapes with densities increasing from the built urban core to outlying residential gardens. Greenfinch (*Carduelis chloris*), and fantail (*Rhipidura fuliginosa*) had lowest numbers at commercial sites followed by residential-detached areas. No goldfinch (*Carduelis caduelis*) or grey warbler was counted in wharf littoral and commercial landscapes. Grey warbler numbers were highest in green landscapes, as were greenfinch and fantail (Figure 2.9).

Patterns in the spatial distribution of tui and silvereye indicate avoidance of wharf littoral and low commercial landscapes, with only single or no observations of both birds in one or other of these landscapes (Figure 2.9). Aggregations of tui and silvereye across residential and green landscape did not vary markedly, but silvereye was more abundant than tui.

Avian abundance was not different across landscape types, although the relationship approached the significance ($F_{5,609} = 1.886$, $P = 0.095$, Partial $Eta^2 = 0.015$) but tests of the interaction between landscape and defining characteristics of each contributing species ecology (a) dominant feeding guild, (b) trophic specialisation, (c) preferred habitat and (d) sociality (Table 1.1) were significant (Table 2.4). The 13 most common and widespread species (Figure 2.5) were analysed. Significant patterns across the four ecological categories within landscape (Figure 2.10) showed fewer gregarious species occurred in green and residential landscapes and roughly equal distributions of species that live alone or in pairs, across all other landscapes. Predators occupied 60 % of wharf littoral sites and around 20 % of residential attached and commercial areas. Only few or occasional predators were recorded in residential and green landscapes. Granivorous feeders occupied more than 60 % of low commercial sites and around 30 % of the wharf littoral zone with an equal distribution across the remaining landscapes.

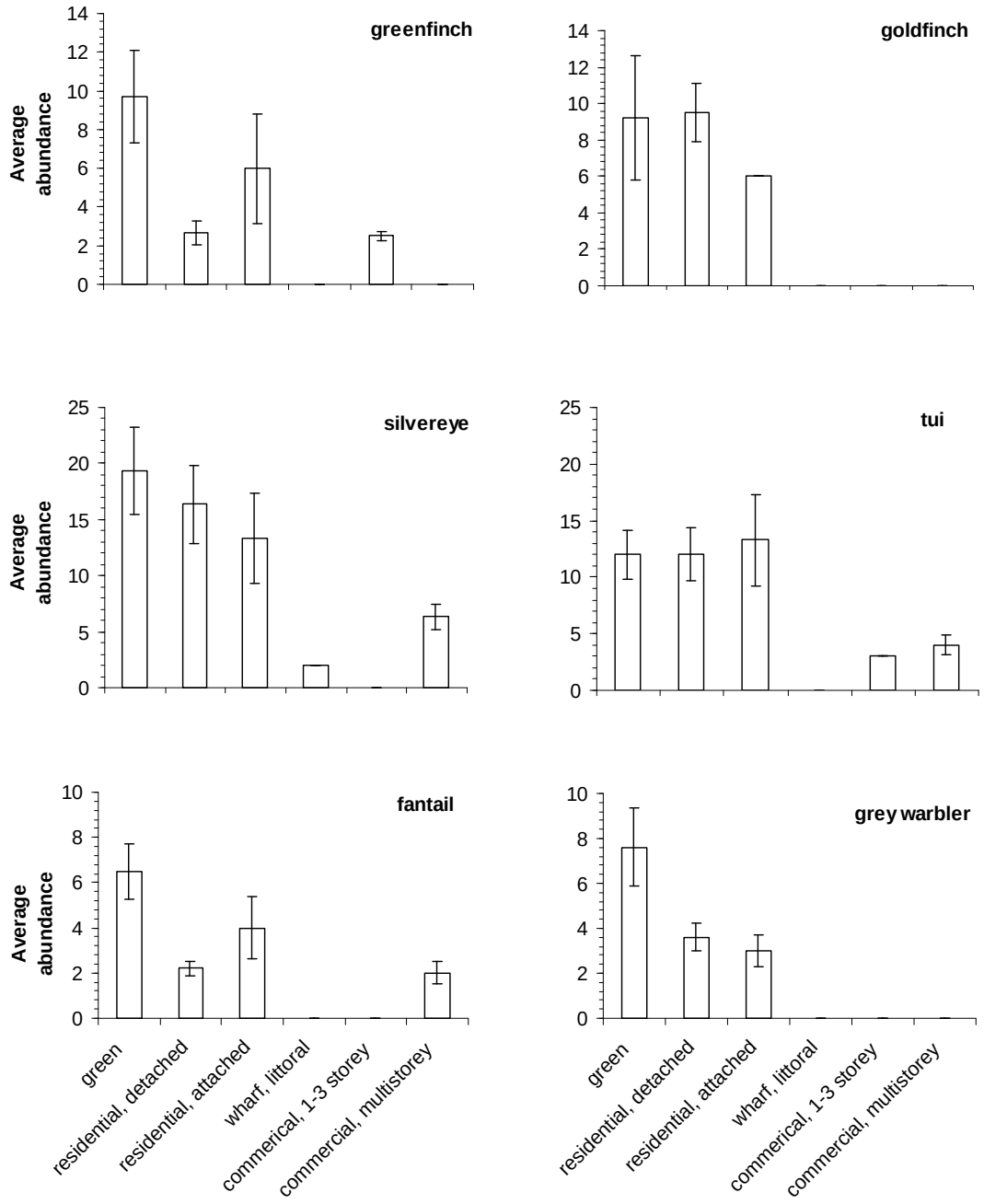

Figure 2.9. Average (± 1S.E.) abundance per strip-transect segment of individuals seen or heard along the six strip-transects conducted over eight walks, from March 2007 to February 2008, for six focal species in the dominant landscape types.

Table 2.4. Summary of statistics (GLM univariate ANOVA) detailing the significance of interactions between characteristics of the species ecology (a) preferred food type, (b) food diversity, (c) preferred habitat and (d) sociality (Table 1.1) with landscape type on avian abundance. The species included house sparrow, starling, black-backed gull, feral pigeon, blackbird, silvereye, red-billed gull, tui, greenfinch, grey warbler, dunnock and song thrush. Partial Eta^2 (variance explained) is defined as the proportion of variance associated with or accounted for by each of the main effects, interactions, and error in the ANOVA (Brown 2008)

Interaction	df	F	P value	Partial Eta^2
Landscape type	5, 609	1.886	0.095	0.015
Landscape type * dominant food	12, 609	7.986	< 0.001	0.109
Landscape type * food diversity	12, 609	13.894	< 0.001	0.215
Landscape type* dominant habitat	12, 609	3.694	< 0.001	0.068
Landscape type* sociality	6, 609	6.401	< 0.001	0.059

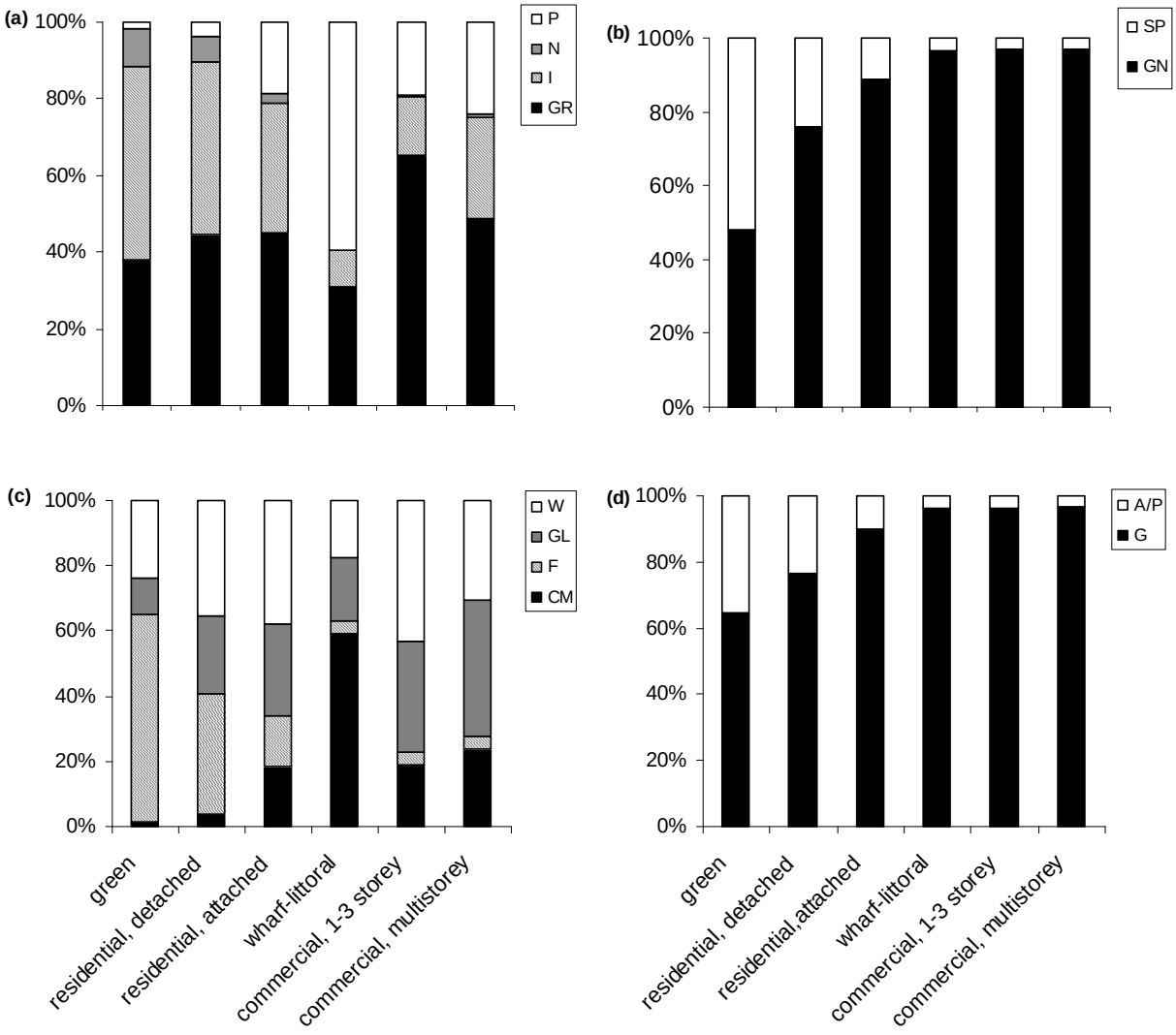

Figure 2.10. Stacked graphs showing the representation of different ecological categories (percentage of individuals) across landscape types, (a) dominant feeding guild – P = predator , N= nectivore, I = insectivore, GR = granivore, (b) trophic specialisation – GN = generalist feeder, SP =specialist feeder, (c) preferred habitat – W = woodland, GL = grassland, F = forest, CM = coastal marine, (d) sociality – AP = alone or pairs, G = gregarious. Figure 2.5 lists the species studied.

The proportion of insectivores was lower at both wharf littoral and low commercial sites. Nectivores were absent or occasional at all sites except green and residential detached neighbourhoods and occupancy of green areas was almost twice that of the residential site. The proportion of generalist feeders was much lower in green landscapes and higher in stages to almost total occupancy of wharf littoral and commercial sites. Significant patterns of dominant habitat across the landscape (Figure 2.10c) showed between 20% and 40% cover of grassland across all landscapes except green sites. Woodlands covered between 20% and up to 40% of all landscapes. Forest habitat covered more than 60% of green landscapes with roughly 30% and 15% cover in the two residential areas. Coastal marine habitat was concentrated in the wharf littoral landscapes with around 20% cover in dense residential and commercial areas.

Temporal richness and abundance of species

The numbers of species (richness) over winter, spring and summer was similar (Figure 2.11). Evening figures over this period showed more variation, with the highest count of 16 species in summer falling to 13.5 in winter. The lowest number of species was recorded in the autumn during evening transects. There was a significant effect of season ($F_{3,40}$ = 6.716, P = 0.001, Eta^2 = 0.335) and time of day ($F_{1,40}$ = 4.598, P = 0.038, Eta^2 = 0.103), but no significant interaction between the two ($F_{3,40}$ =2.416, p =0.081).

Blackbird showed a clear peak of abundance in spring; house sparrow and silvereye had highest counts in summer. The abundance of grey warbler, starling, feral pigeon and black-backed gull did not vary seasonally, but their numbers were different during the day. Numbers of housesparrow also varied with time of day. Tui numbers were

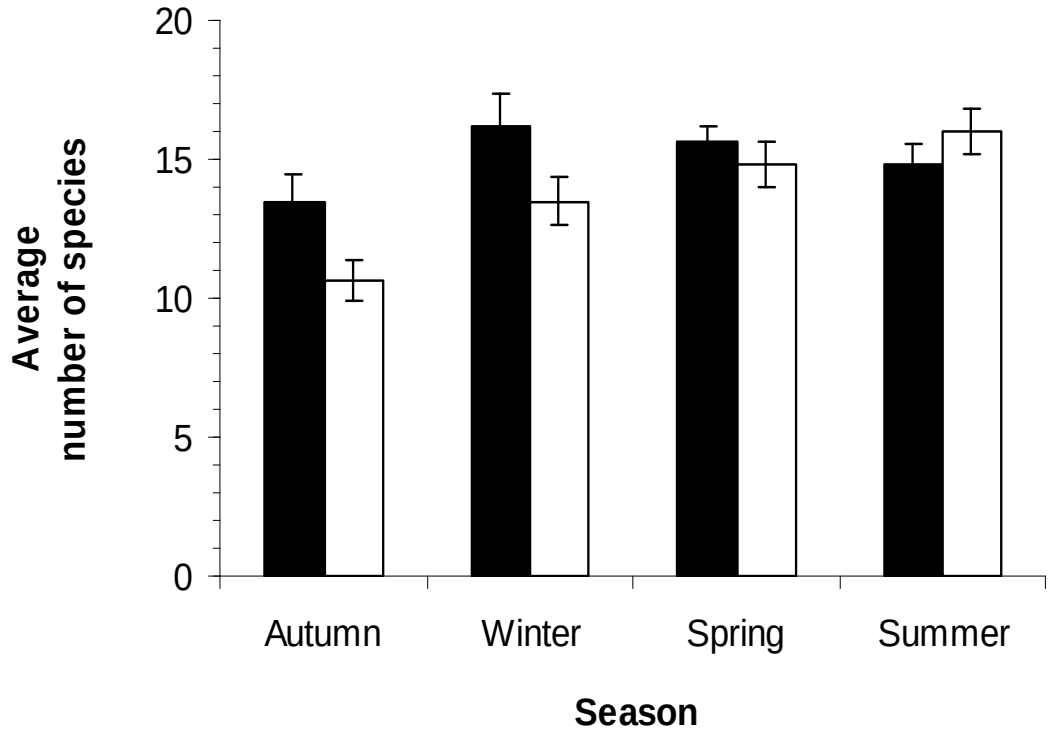

Figure 2.11. Average (± 1S.E.) number of species along the six strip-transects during the morning (■) and evening (□) over seasons of autumn, winter spring and summer, from March 2007 to February 2008.

higher but similar across winter to summer, but fluctuated more with day period. Fewer tui were counted in autumn. Numbers of red-billed gull were low through spring to autumn. Greenfinch numbers were low but steady in winter and spring with a small summer peak suggested. Overall the low numbers counted and consequent high variability between counts for goldfinch and fantail prevented the definition of clear seasonal patterns but generally goldfinch numbers were similar during spring and summer, and either low or highly variable in autumn and winter (Figures 2.12 and 2.13).

Abundance counts varied with time of day for four species. Counts of starling were higher in the evening period, while higher counts of tui and grey warbler were recorded in the morning. Lower but less variable numbers of feral pigeon were counted during the evening.

Species abundance did not change with season ($F_{3,64} = 0.330$, $P = 0.804$, $Eta^2 = 0.015$) but did vary with time of day ($F_{1,64} = 4.182$, $P = 0.045$, $Eta^2 = 0.61$) and there was no interaction between the two ($F_{3,64} = 0.237$, $P = 0.870$, Eta2 = 0.11). Only the interaction between season and species feeding diversity was significant in modifying abundance amongst species across the landscape. Other relationships (species dominant food and species sociality) were weak although approaching significance (Table 2.5). Slightly higher numbers of specialist feeders were recorded in spring (Figure 2.14c) and a small increase of granivorous species occurred in summer (Figure 2.14b). Also slightly lower proportions of gregarious species were recorded in spring and winter (Figure 2.14b). There was a small shift in species abundance with time of day between autumn and winter (Figure 2.14a).

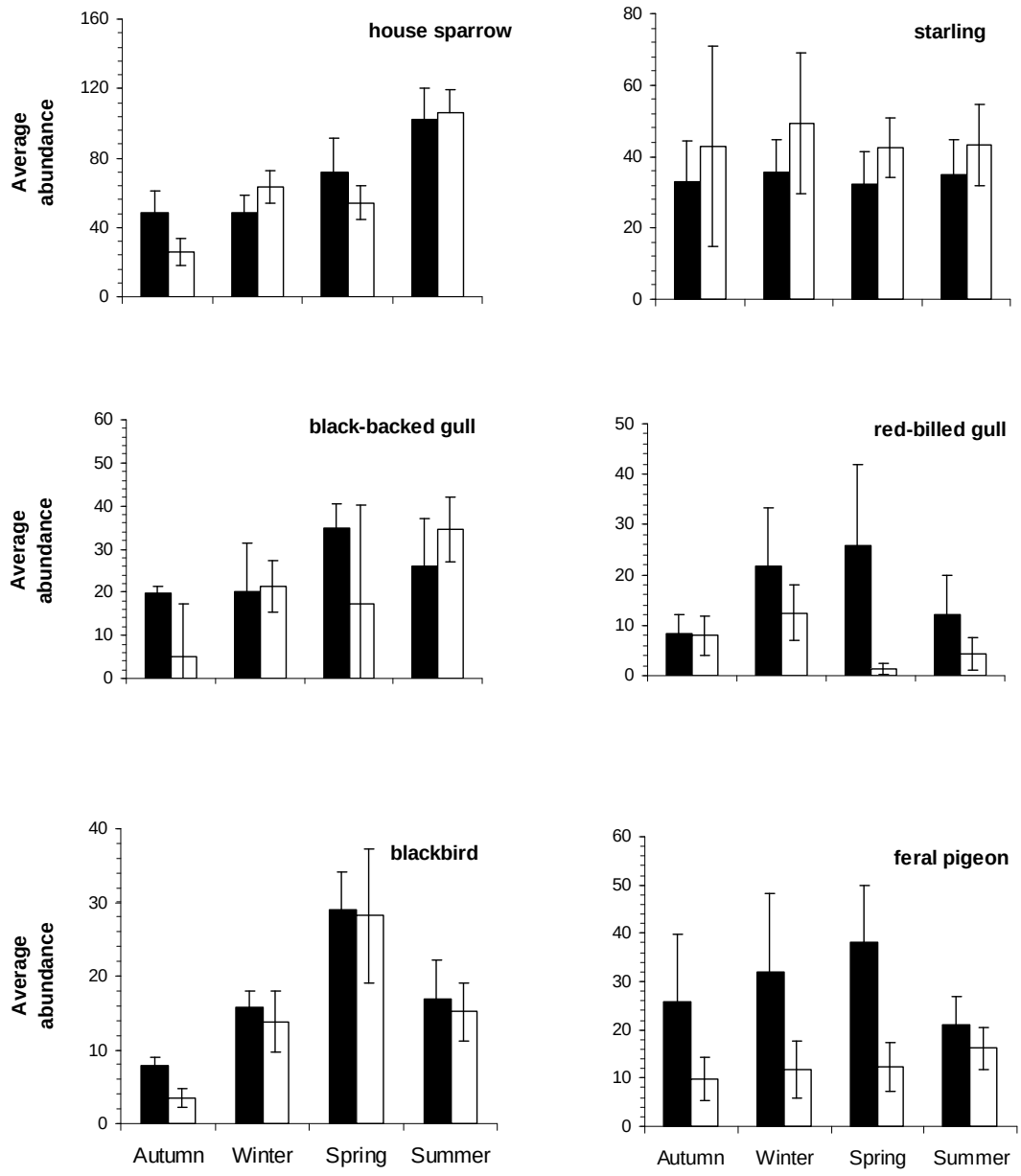

Figure 2.12. Average (± 1S.E.) abundance of individuals that were seen or heard along the six strip-transects that were conducted over eight walks, for six focal species in autumn, winter, spring and summer during the morning (■) and evening (□) periods.

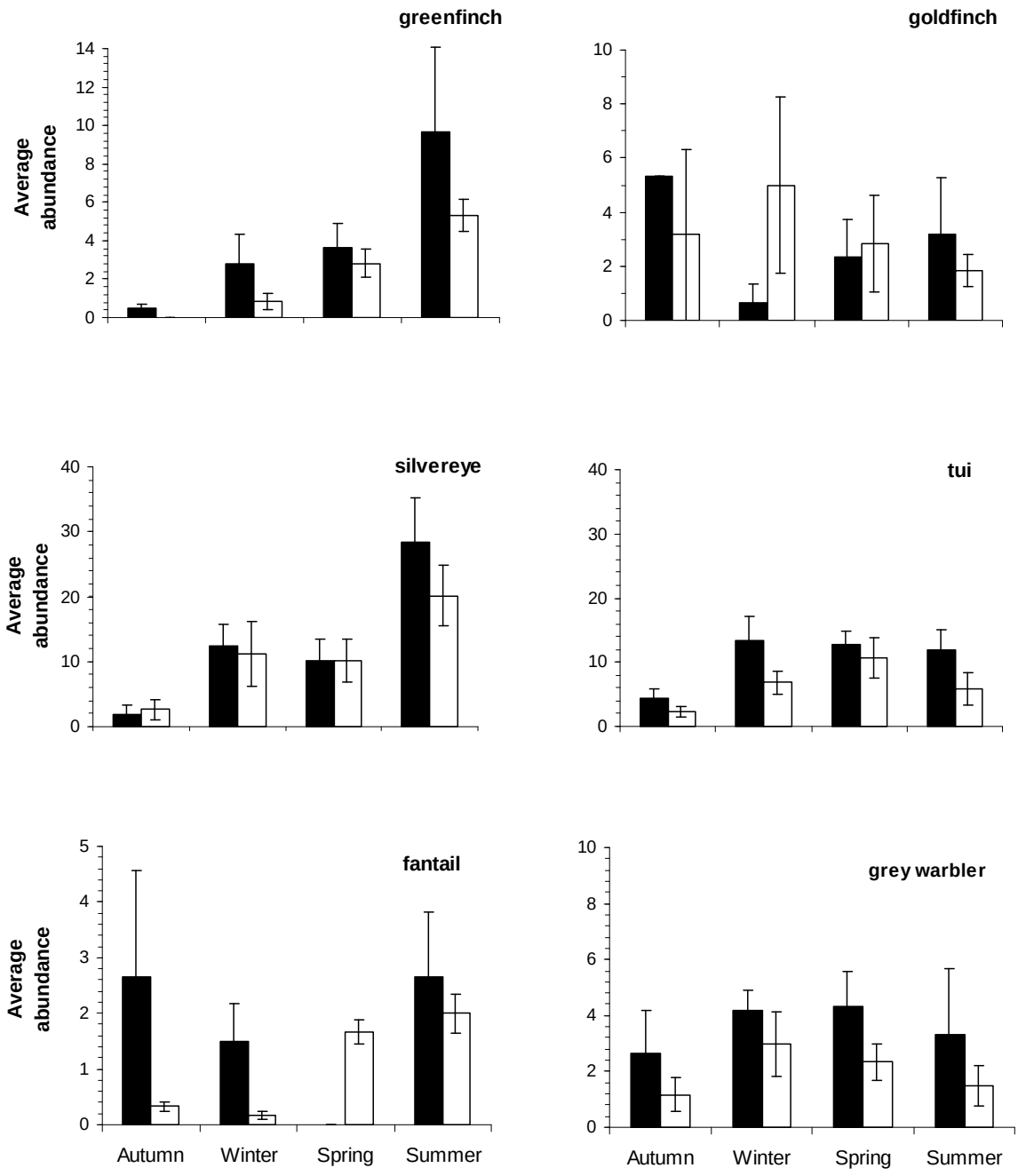

Figure 2.13. Average (± 1S.E.) abundance of individuals that were seen or heard along the six strip-transects that were conducted over eight walks, for six focal species in autumn, winter, spring and summer during the morning (■) and evening (□) periods.

Table 2.5. Summary of statistics (GLM – Univariate ANOVA) of: (i) the effect of season and time of day (T.O.D), and (ii) the interaction between the species ecology (i.e. sociality, preferred food and food diversity) with season or avian abundance. The species included in this analysis were house sparrow, starling, black-backed gull, feral pigeon, red-billed gull, blackbird, silvereye, tui, greenfinch, goldfinch, grey warbler and fantail.

Interaction	df	F	P value	Eta^2
Season	3,64	0.330	0.804	0.015
Time of day	1,64	4.182	0.045	0.061
Season*time of day	3,64	0.237	0.870	0.011
Season*sociality	4,64	2.043	0.099	0.113
Season*dominant food	12,64	1.776	0.071	0.250
Season*diet diversity	8,64	7.830	<0.001	0.495

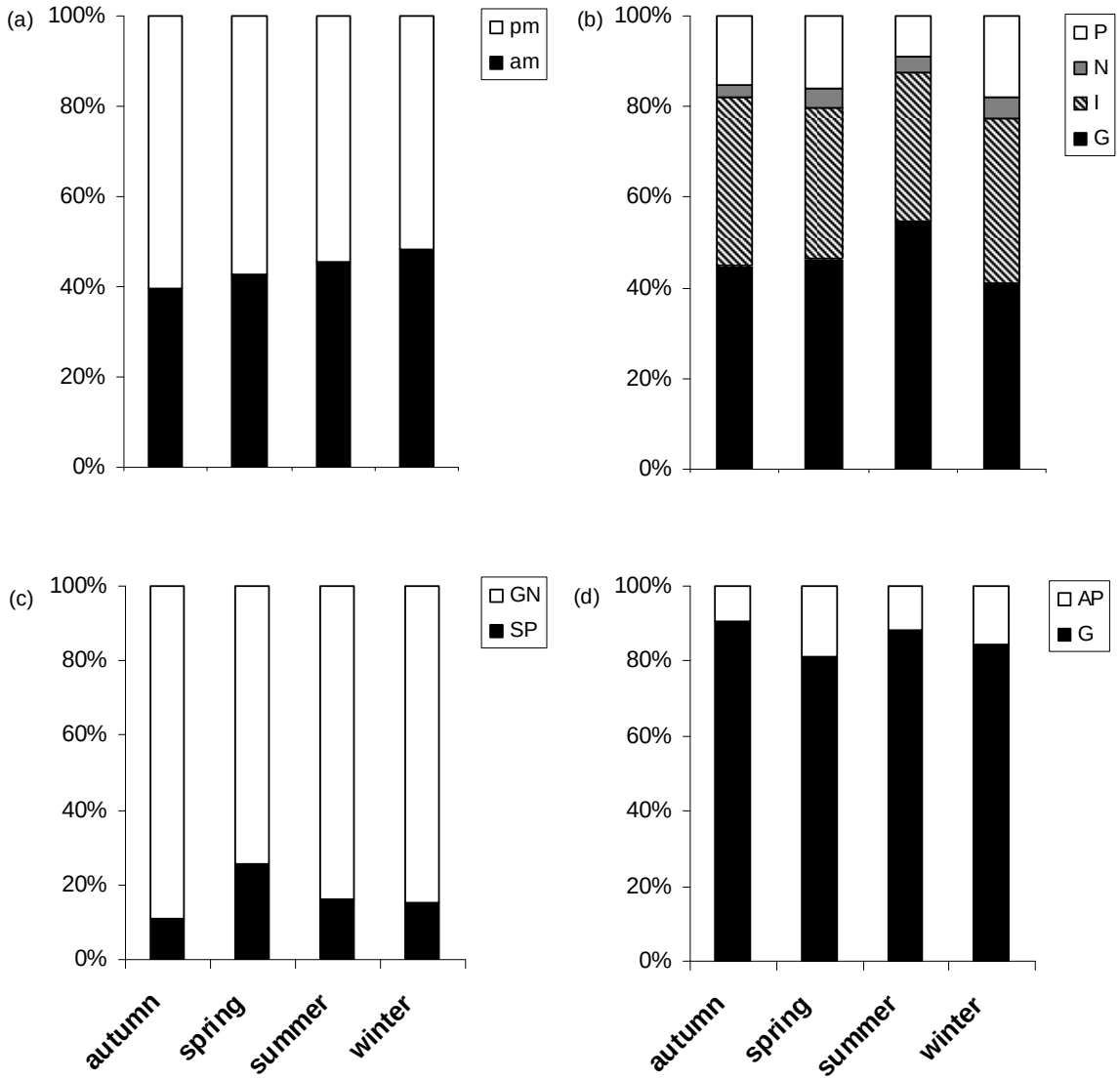

Figure 2.14. Stacked graphs showing (a) interaction between time of day and season, and the representation of different ecological types (percentage individuals) across season, (b) dominant feeding guild, (c) trophic specialisation and (d) sociality for avian abundance. Figure 2.5 records the species studied. See Figure 2.8 for codes of the ecological type.

Discussion

Species richness of the avian community in urban Wellington changed with landscape type. Green and less built landscapes supported a greater variety of species than the more highly built central business district. Species richness remained similar across the seasons and at time of day. However, the abundance of particular species varied across the different landscapes and fluctuated across seasons. Seasonal peaks at breeding times were more apparent for some species than others.

Species occurrence, richness and abundance

A few species like housesparrows and starling constituted most individuals counted and were most widespread. Others like blackbird, chaffinch, tui and silvereye were less common but similarly widespread. Most species however were rare and occupied fewer strip-transect segments. Occupancy of sites can be understood by the ecology and capacity of a species to tolerate conditions of disturbance and their ability to utilise smaller fragments of habitat that make up the urban environment. For example, house sparrow, starling and blackbird occupied around 96% of all strip-segments. House sparrow feed and roost communally in large flocks and their ecology is now closely associated (commensal) with people. Blackbird are more solitary but their occupancy across all strips indicated that they were able to utilise discrete elements of all suitable habitat. Starling are gregarious throughout the year and generalist in their feeding. These widespread ‘urban-exploitive’ and abundant species are all exotic and introduced to New Zealand. Nevertheless other urban adaptable species included the native tui and silvereye. Both are generalist in their feeding and historically inhabit either forest or woodland. Generally, species that were limited in occupancy of strips were specialists in both their habitat or food requirements, for example, species such as kaka that require areas of dense

forest and the availability of mature or decaying trees to nest. Species with a broader range of habitat and more generalist in their food intake were more likely to be found in the more urbanised or built landscape types.

Landscape types as defined in my study were significant for the avian community in Wellington City in determining the numbers of different species that were recorded. My results generally agree with the literature (Blair 1996, 2001; McKinney 2002) and confirm my hypothesis; that species richness decreases as the proportion of built landscape increases. It is relevant that across the study area green spaces inter-digitated with more built landscapes and that all landscapes were contiguous. This structuring of landscape promotes environmental heterogeneity (McKinney 2002) and in general supports a greater mix of species. The mix of species in green landscapes included both native and introduced birds: blackbird, greenfinch, goldfinch, silvereye, fantail, grey warbler and tui. A novel finding in my study is suggested: that multi-storey commercial landscape supported slightly greater numbers of species than low commercial sites. The avian community here included the native forest species, silvereye, tui and fantail, most likely because of mixed plantings of flowering exotic and native trees attracting tui, and lower maintenance bark and woody, or shrub gardens providing habitat for silvereye and fantail. The environment within and surrounding the Wellington hospital grounds provided such a habitat.

Greater landscape diversity at a site did not support higher numbers of species. I predicted the reverse – that diversity of landscapes would support richness of species. Two explanations are suggested. First, it is possible that low species richness recorded at one of two segments delineated by residential attached sites (with a richness of 5) (Figure 2.7) is driving this relationship and suggests that this landscape is depauperate for birds. I recall however, that each point identifies only the dominant landscape and included a mix

of more disturbed landscapes such as light industrial and high commercial areas. It is possible that the highly heterogeneous nature of urban systems influences species richness, either positively or negatively, and that the precise mix of these landscapes in fact determines species richness not diversity per se. The second point is simply that these strips of landscape may be too small to provide sufficient habitat to support a greater number of species. This suggests that greater landscape diversity reduces landscape utility.

Of the six most common birds only silvereye and blackbird can be broadly termed forest species. Both birds are insectivores and supplement their diet with fruit (Cramp 1988; Higgins et al. 2001) but the presence of a mix of vegetative cover and open ground is the essential element of their habitat rather than continuous forest habitat. Distribution patterns of these two species were similar: most individuals were located in residential and green landscapes, but greater numbers of blackbird utilised residential detached sites while silvereye favoured green landscapes.

Native forest or forest, scrub and shrubland birds include silvereye, fantail, tui and grey warbler (also edge of forest) (Higgins & Peter 2002; Higgins et al. 2001). Apart from tui, a partial nectar feeder, all are insectivores. All showed a classic descending abundance distribution – from green to residential attached with rare occasions of being counted in more built habitat. Nevertheless they, especially tui, might be good examples of what Blair (1996) terms ‘suburban adaptable’. Their distribution was even across green and residential detached landscapes but slightly higher in residential attached neighbourhoods where it was able to utilise exotic vegetation like eucalyptus and banksia (*pers obs*). Grey warbler, a more cryptic species and less tolerant of disturbance than fantail (*pers obs*) showed a truncated and more skewed distribution: they were absent from more built areas and primarily inhabited green landscapes. Fantail, like silvereye

and tui were observed in commercial multi-storey areas. This illustrates the ability of these birds to utilise small fragments of habitat (native plantings) within the larger mosaic and therefore suggests the possibility that fantail may also be suburban-adaptable.

General woodland, edge and grassland species include the group of medium sized birds that are granivorous. The goldfinch is more specialised in the type of seed it eats; this is reflected in its restricted distribution across the landscapes and preference for suburban gardens (Figure 2.9). The greenfinch prefers woodland that is more densely leaved but also uses grasslands. Its distribution is more patchy but less restricted than goldfinch. Starling, house sparrow and feral pigeon share aspects of their ecology. All are generalist in their feeding and have benefited from the human modified environment and house sparrow and feral pigeon are commensal with humans. They are also gregarious, either colonial or communal in sociality and are able to utilise tall structures such as buildings for nesting and roosting. Predictably house sparrow had highest abundance in low commercial areas, feral pigeon utilised both commercial landscapes equally, while starling preferred the commercial central business district using the linear arrangement of tall buildings and roadside trees for roosting.

Large numbers of gulls aggregated in the wharf littoral landscape that in my study lay directly adjacent to the commercial precinct. Black-backed gulls are mainly confined to coastal and estuarine habitat while red-billed gulls ranged further out to sea (Heather & Robertson 1996). Both species have benefited from human settlement and activity (Heather & Robertson 1996). As opportunist scavengers these birds have a good food supply made available from commercial fishing, sewers and rubbish tips. They also use buildings (ledges) and other vertical structures for roosting (*pers obs*).

A species' native ecology modifies where it occurs in urban landscapes and its abundance there. Predatory and scavenging feeders were predictably dominant in their

favoured habitat (coastal marine). They also aggregated in residential attached and commercial sites because these sites are close to the harbour, near water, and are densely built with a surplus of waste bins and food scraps due to the higher percentage of foot traffic, restaurants and cafes that are characteristic of this landscape. The higher proportion of granivorous species, especially house sparrow, within commercial sites reflects the gregarious sociality of these birds and their high tolerance of humans. Also, from my observations, I suggest that the large surface area in rooftops as territory for breeding, and pavements and gutters as seed traps for foraging, are an ideal environment for these birds. The wharf littoral landscape has limited rich habitat for ground feeding insectivores, as most surfaces here are impervious and so woodland and forest species including finches and tui were predictably uncommon there. Specialist feeders that also typically live in pairs or alone are more abundant in green landscapes because this environment offers richer ground cover and more concealed or protected sites for nesting. Predictably green landscapes therefore supported more individuals of species that associated as pairs or alone.

Temporal abundance and richness of species

Species richness was the same from winter to spring. Results for autumn are depressed, however I suggest this is a reflection of sampling rather than an indication of trend. At this early stage of my project errors in species detection may have occurred, particularly in forest habitat and occasions of dull light when aural identification of species became necessary. There is an effect of both season and day period for the numbers (richness) of species.

The abundance of species in landscape types is influenced by season and time of day. Three different hypotheses are suggested to explain these fluctuations. Firstly,

abundance may increase due to breeding that extends for these species from August through to March. Second, I expect some species to move into and out of different landscapes within Wellington in response to food supply and lastly, the conspicuousness of most species changes with season (Dawson 1981; Dawson et al. 1978). Breeding activity and the presence of fledglings most likely contribute to peaks of abundance for sparrow, greenfinch and fantail as breeding commences early in spring. I suggest that the higher numbers of silvereye in summer occurs too early to be due to breeding but rather that these birds move into urban Wellington landscapes in response to seasonal variation in food supply (Heather & Robertson 1996). The higher morning counts for goldfinch and silvereye in summer indicate this time is the optimal period for foraging. Higher numbers of blackbird in spring more likely can be explained by pre-mating behaviour that increases their visibility and therefore counts, rather than the breeding. Territorial song and defence of territory occurs from July (Crowe 2001; Heather & Robertson 1996). They also engage in calling and advertising for mates. Patterns for goldfinch are erratic for autumn and winter – goldfinch are mobile seasonal feeders and will move considerable distances in search of the different seeds they eat as these ripen (Cramp et al. 1994). It is likely then that the higher abundance counts during this period represent flocks at a local food supply. Flocking to feed also explains the variation between counts because individual aggregation of birds elevates variance. Therefore, whether or not a species flocks to feed, will influence spatial patterns of abundance.

Abundance across seasons was even for tui (discounting autumn) and grey warbler (Figure 2.13). Counts of both species were generally higher in the morning foraging period. It is likely that visibility is also a factor contributing to variability in counts for these species. With denser vegetative growth in spring and summer and more plentiful food supply in autumn, these birds that typically feed above ground in the canopy, would

be less conspicuous. Most detection of grey warbler and to some extent tui was aural. This means that frequency of song or calling will influence detections and therefore abundance. Timing (earlier as the days lengthen) and length of song varies with season and stage in the mating cycle (Best 1981; Dawson 1981). Also when food is abundant, as in mast years for flowering trees, the birds are less mobile and quieter, spending more time feeding.

The common urban species – house sparrow, feral pigeon and gulls have largely modified aspects of their ecology and are now commensal. The uniform seasonal abundance of black-backed gull, starling and feral pigeon suggests no breeding peak but rather that these birds are sedentary remaining in the city all year round. Higher abundance of starling in the evening period is possibly an effect of high numbers of these birds flocking to roost on building ledges and rows of taller trees along roads within the inner city environment. In contrast, a morning effect on abundance of pigeon suggests large aggregations of pigeon collected to scavenge on food scraps outside the many food facilities, while in the evening they flew elsewhere to roost. House sparrows are a highly social species that feed in groups. It appears there is a summer peak synchronous with breeding, but the high counts also reflect high visibility. Sparrows flew in large flocks with starling to roosts in summer, and in late summer they were also observed in large flocks feeding with blackbird and starling in open grassy areas. Higher numbers of both gull species were counted adjacent to the coast; a peak during spring and summer for black-backed gulls coincides with breeding. Large aggregations of gull were not observed away from the coast (i.e. a coastal pattern).

The species' ecology did not markedly influence abundance of species at time of day across season. The slightly lower evening counts in winter most likely were due to the earlier time birds flew to roost, but also to less bright light conditions that reduced

visibility. The increase in spring of specialist feeders that may also be territorial indicates that these species are foraging more actively and most likely engaging in territorial displays for mating, both of which increase their visibility. There was slight increase of species that live alone or in pairs (i.e. territorial) in spring.

Conclusion

In this study landscape type (classification) modified avian biodiversity in the urban area that extended to a five-kilometre radius around the central business district of Wellington City. Average species richness was highest in green landscapes and less in stages to wharf littoral and commercial sites. Landscape diversity or the number of landscapes within an area did not modify avian biodiversity. Landscape classification did not influence total avian abundance but there was variation among species about when and where they were abundant. Some species were more abundant in less built areas and some were more abundant in more built areas. Some species were present all year round while others changed in abundance with season, particularly in spring and summer. Abundance fluctuates across the landscape because of, or in response to, the species ecology, namely dominant food type, food diversity, dominant habitat and sociality. Food diversity particularly influenced seasonal abundance of species.

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Chapter 3: The role of fine scale patch structure on bird biodiversity and abundance in Wellington City

Abstract: I address the question of whether fine scale patch dynamics influences bird species richness and abundance in urban settings composed of a diverse mosaic of variously built and unbuilt habitat. In particular I investigated how habitat patch size and diversity influence species diversity and occurrence of abundance. I used the five-minute bird count (FMBC) method to count birds at 49 locations along six transects located within the Wellington central business district and visited each point eight times between March 2007 and February 2008. I used Arc GIS to analyse habitat patch types in the 100 m area surrounding FMBC. A total of 34 bird species and 5690 individuals were recorded in FMBC's. I found that avian communities in the Wellington urban area were dominated by six common species but that many more species were present in much lower numbers at fewer sites. Biomass of birds in FMBC's increased with movement towards the built commercial centre and higher density housing areas but species richness increased with distance from the built centre to residential and green sites. I found no relationship between species richness and the total number of individuals present at any point, and the total biomass and abundance of birds was also independent of patch size. Average patch size showed a weak positive relationship with species richness but species richness was independent of habitat patch diversity. The abundance of some individuals in their favoured patch type did vary in response to patch structure with the strongest relationships seen for blackbird and sparrow. These results suggest that fine patch structure within the urban setting is not a major influence in driving bird biodiversity but that more importantly birds are responding to cues at the larger scale of landscape.

Introduction

Urban environments have diverse composition of habitat. Cities introduce novel habitats such as lawns, gardens, buildings and roads (Emlen 1974) as a mosaic of patches. These new habitats occur at the expense of historic original and less modified habitat that remains only as remnant patches that also contribute to the mosaic. This landscape of patches is colonised by any birds able to utilize its parts and survive (Emlen 1974), and ultimately leads to changes in the composition of the avian community.

This chapter investigates how the composition of patches influence avian community richness and abundance. A species uses a patch to the extent that it provides sufficient food, water or shelter. The most important characteristic of the habitat patch in determining its ability to support species diversity is its area. The literature has debated this characteristic in the design of reserves because the number of species and abundance tends to increase with increasing patch size (Connor & McCoy 1979; Diamond 1975; MacArthur & Wilson 1967). Secondarily, habitat richness or heterogeneity is expected to support greater species richness (Bunnell 1999). At the finer scale, in studies of temperate forests in unmodified landscapes both area and heterogeneity of habitat fragments were found to be important in determining avian community structure (Freemark & Merriam 1986). Bunnell (1999) describes the interaction between area and habitat heterogeneity and calls it the “area effect” where larger areas have more diverse and larger patches of habitat and therefore more potential niche sites to host greater numbers of species and individuals.

In the urban environment, the relevance of the landscape setting or dominant surrounding land use has also been shown to be an important influence of species richness and abundance (Melles et al. 2003). This study found an effect of landscape type with less

built landscapes supporting higher species diversity but not abundance. Rather, abundance was dependent on the species ecology and therefore specific to landscape types irrespective of how urbanised they are. (Chapter 2, results, Figure 2.6). The question to be answered then is whether fine scale patch dynamics also apply and influence bird species abundance and richness in urban settings composed of a diverse mosaic of variously built and unbuilt habitat.

The aim of this chapter is to investigate how avian species richness and abundance changes in relation to variation in habitat patch size, structure and diversity. My hypotheses are that (i) the total biomass of birds, (ii) the total number of individuals, and (iii) species richness will increase with the size of the largest local patch. I also expect a positive relationship between local habitat patch diversity and species richness. Finally I predict that the number, the largest size and total area of a species favoured habitat will relate positively with avian abundance.

Methods

Point locations were located at 400-metre linear intervals along six transects from the central to the periphery of the city (Figure 2.1) to provide a total of 49 sampling points. The initial point on each strip was randomly selected. I conducted 5-minute bird counts (FMBC) (Dawson & Bull 1975) at each point in sequence every month from March 2007 to February 2008 (see Chapter 2, Methods, Table 2.2). The FMBC offers a robust means of gaining a comparative measure of what birds are present in an area, particularly for common species and passerines (Hartley & Greene 2008). The advantages of the method outweigh its limitations. For example, it offers a cheap and effective way of conducting repeated and controlled counts at marked sites over time for comparison. In New Zealand the FMBC is the standard and most widely used method of avian community monitoring (Hartley & Greene 2008). For example the Department of Conservation (D.O.C.) uses it in conjunction with large-scale pest control operations to monitor changes in abundance of native passerines and in Europe and the U.S.A. it is the method of choice for the many Breeding Bird Survey (BBS) programmes (Spurr 2005).

During each FMBC I recorded all birds seen or heard during a five-minute period. All species detected, at all distances from the observer were recorded (unbounded counts). Individual birds were counted only once during the five-minute period. Environmental conditions were described, including wind, rain, temperature, and light intensity for each FMBC. Wind was described for the duration of the five-minute count using a modified Beaufort scale (Hartley & Greene 2008) with 0 – leaves are still or move without noise, (Beaufort 0 and 1), 1 – leaves rustle (Beaufort 2), 2 – leaves and branches in constant motion (Beaufort 3 and 4) and 3 – branches or trees sway (Beaufort 5, 6 and 7). Sampling was not undertaken in heavy rain or strong winds. Precipitation was

recorded on a scale from zero (0) to 3, with 0 as no rain, 1 as dripping foliage, 2 as drizzle and 3 as light rain. Temperature was assessed as cold < 6 ºC, cool 6 –10 ºC, mild 11 – 15 ºC, warm 16 – 22 ºC and hot > 22 ºC (Hartley & Greene 2008). Ambient noise was assessed on an ordinal scale, from zero (no noise), 1 (low background hum), 2 – 3 (moderate e.g. low volume traffic), 4 (constant loud and disruptive e.g. high traffic volume). Intensity of light was noted as bright (full sun), medium (partial cloud) or low (heavy cloud or late dawn, early dusk).

Analysis on ArcGIS

Most birds along transects (Chapter 2, Methods) were seen within 50 metres of the observer so this was selected as the radius of the area around the FMBC in which to describe habitat patch composition and structure. Habitat patches were defined by homogeneous land cover that was present in the 50m radius around the FMBC sampling point (Table 3.1.) and were selected as discrete areas that displayed comparatively uniform land cover. Eight habitat patch types were identified and defined. These included lawn, trees, a mix of trees and lawn, ruderal vegetation, rooftops, sealed surface-roads, sealed surface-paving and marine. I separated the patch type sealed surfaces because roads are subjected to greater vehicle use, are continuous and more exposed than paving. Also sealed surface-paving habitat patches have more surrounding vegetation and are used socially by people for markets and entertainment and this creates a different microenvironment.

Table 3.1. The name and definition of habitat patches delineated in the 49 five-minute bird counts.

Habitat type	Habitat description
Lawn	An area of mowed grass.
Trees	An area of trees including forest, scrub and individual trees.
Trees and lawn	A mixed area of trees and lawn.
Ruderal	An area of tall weed, wild herbs and rank grass.
Rooftops	The upper surface of all buildings.
Sealed surface-road	All paved roadways used by vehicles.
Sealed surface-paving	All other paved areas such as car parks and recreation areas.
Marine	The coastal zone, including harbour frontage and beaches.

Using ArcGIS version 9.1, an aerial map of Wellington at a resolution of 1:2,500 metres, (Land Information New Zealand 2007) was used to provide a background geo-referenced map (Figure 2.1) and waypoint co-ordinates (NZTM 2000 eastings and northings) marking each FMBC point were imported onto the map. Patches within the 50m radius area surrounding the FMBC sampling points were digitised from higher resolution maps located at these points that were obtained from Wellington City Council (WCC). They were re-sampled to a resolution of 0.6m and patches of habitat types digitised within the 50m areas. Where a habitat patch extended beyond the 50 metre boundary, they were digitised to the 100 metre boundary (Figure 3.1). Habitat patches that are infinite, such as roads and the sea were digitised to the 50m radius boundary only. For each 100-m radius sampling area the following measures of habitat structure were calculated for all habitat types: a total count of patch number and habitat types (the number of different habitats), the average patch area, and the size of the largest patch local to each FMBC. The bird community was characterised by: the total number of individuals, as well as the sum of the biomass in grams (Crowe 2001; Heather & Robertson 1996) of all birds seen or heard. In addition, the count of species richness in each FMBC was calculated.

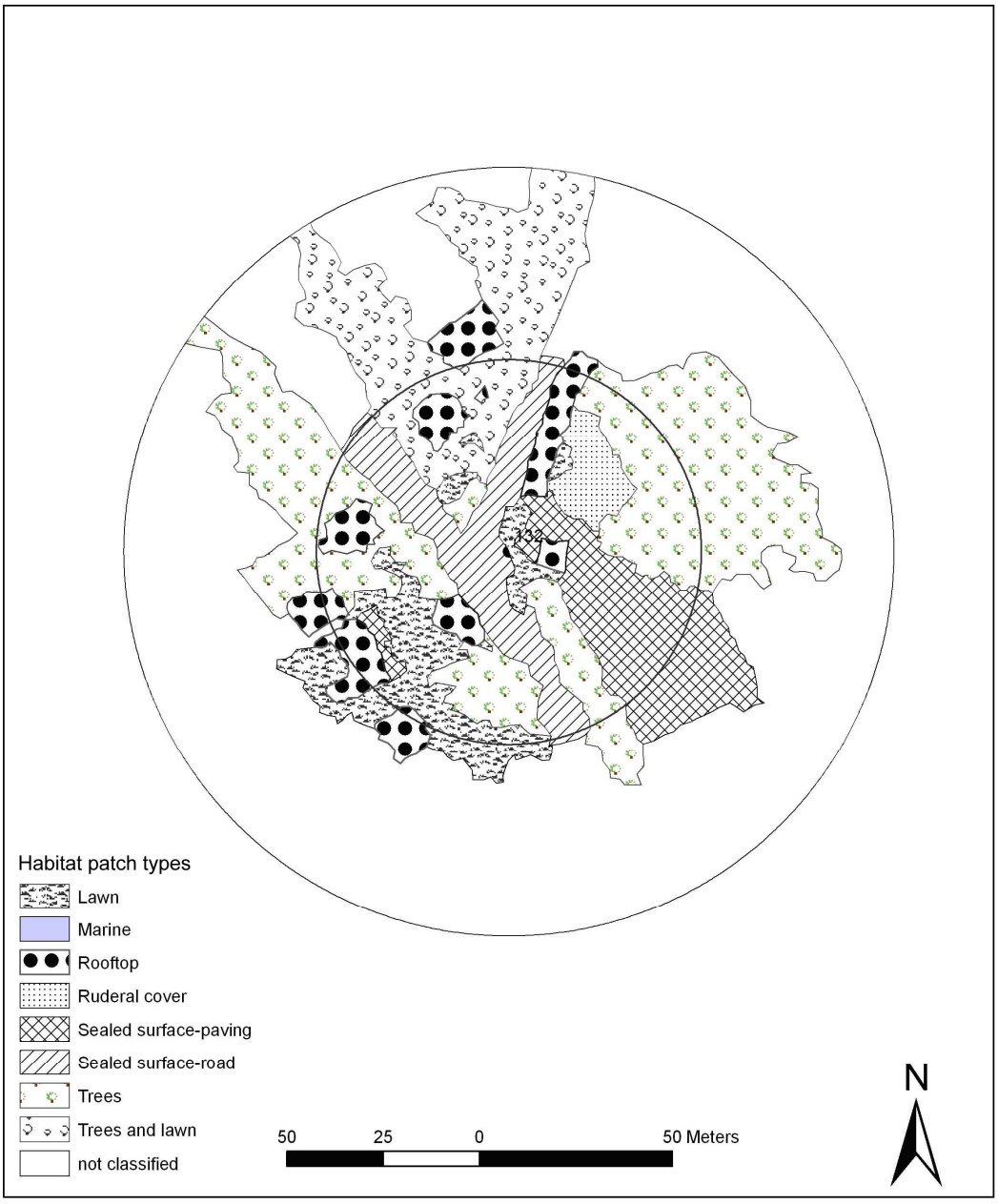

Figure 3.1 An example of one FMBC sampling point and how its surrounding habitat was described. The outer circle defines the 100-m area and the inner circle the finite 50 m radius boundary. Habitat patches like roads were digitised to the 50m boundary, and other habitat types up to the 100-m boundary if they extended beyond the 50 m boundary.

Statistical Analysis

Data were analysed using regression analysis and the multivariate regression, backward selection procedure on the SPSS statistical programme. Regression analysis was used to test the relationship between species richness and (i) the total number of individuals, (ii) average patch size and (iii) habitat patch diversity. The relationship between average patch size and the total biomass of individuals in patches was also tested using regression analysis. The multivariate regression, backward selection tested the model of how much of the occurrence of a species abundance in its preferred habitat was explained by the variables of (i) patch number, (ii) largest patch size and (iii) the total area of patch cover. The correlation coefficient r gave a measure of how precisely the data fitted the models used. Statistical significance was assumed at $p < 0.05$ and alpha values <0.1 were examined as possibly indicating a weak trend.

Results

Thirty-four bird species and 5690 individuals were recorded in FMBCs over 12 months. Species occupancy showed a positive exponential relationship (Figure 3.2). The house sparrow (*Passer domesticus*: Ploceidae) was the most common and widespread species with 1427 individuals' in 47 FMBC sites. The starling (*Sturnus vulgaris*: Sturnidae) occupied all FMBC with 1088 individuals, followed by black-backed gull (*Larus dominicanus*: Laridae) and feral pigeon (*Columba livia*: Columbidae). The blackbird (*Turdus merula*: Muscicapidae) was widespread, as were tui (*Prosthemadera novaeseelandiae*: Meliphagidae), chaffinch (*Fringilla coelebs*: Fringillidae) and silvereye (*Zosterops lateralis*: Zosteropidae). The red-billed gull (*Larus novaehollandiae*: Laridae) was more restricted in range occupying only 47 percent of FMBC sites. Dunnock (*Prunella modularis*: Prunellidae), greenfinch (*Carduelis chloris*: Fringillidae) and grey warbler (*Gerygone igata*: Acanthizidae) had low numbers but were present in about 50 % of FMBCs. Counts of abundance along the six sampling routes (Figure 3.3) showed the greater biomass of birds concentrated at FMBCs within the built commercial centre and surrounding higher density housing areas. Counts of richness (Figure 3.4) however increased with distance from the built centre to residential and green landscape types (Chapter 2).

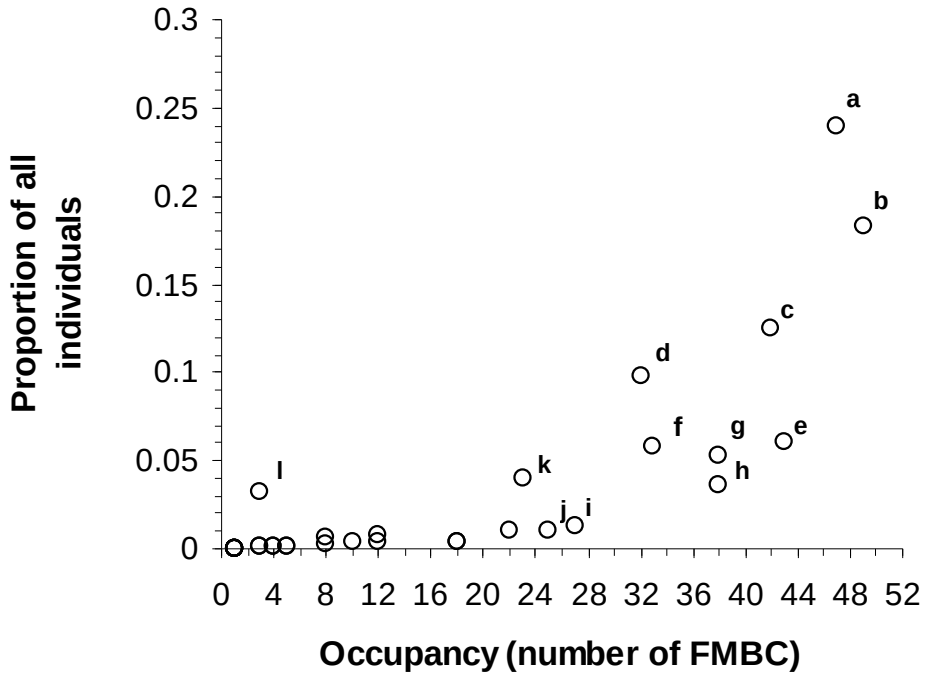

Figure 3.2. Proportion of FMBC (N = 49) occupied by different bird species. The 13 most common and/or widespread species were (a) house sparrow, (*Passer domesticus*) (b), starling (*Sturnus vulgaris*) (c) black-backed gull (*Larus dominicanus*: Laridae), (d) feral pigeon (*Columba livia*), (e) blackbird (*Turdus merula*), (f) silvereye (*Zosterops lateralis*), (g) chaffinch (*Fringilla coelebs*), (h) tui (*Prosthemadera novaeseelandiae*), (i) greenfinch (*Carduelis chloris*) (j) dunnock (*Prunella modularis*), (k) red-billed gull (*Larus novaehollandiae*), (l) mallard (*Anas platyrhynchos*). (See Appendix 2 for raw data used to construct this graph).

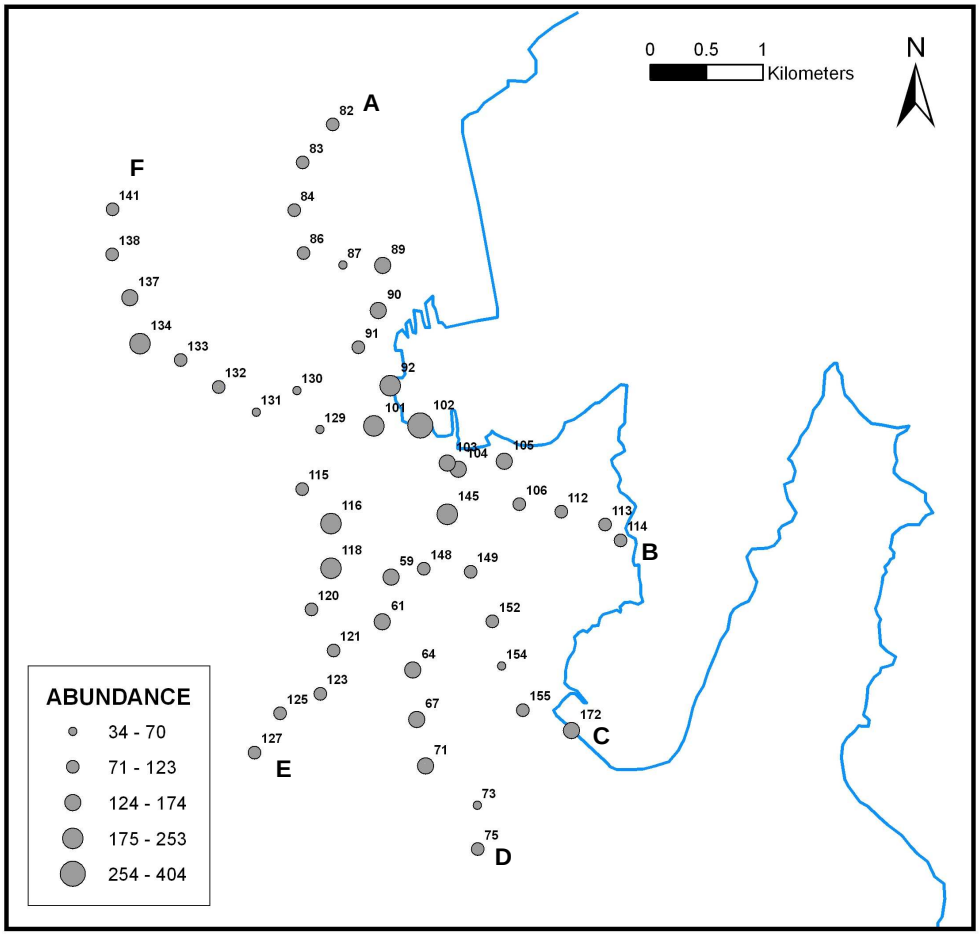

Figure 3.3. Count of avian abundance at the 49 FMBC points along the sampling routes A to F over the period from March 2007 to February 2008. Each FMBC was visited 8 times over this period. The FMBC points are numbered along each of the routes.

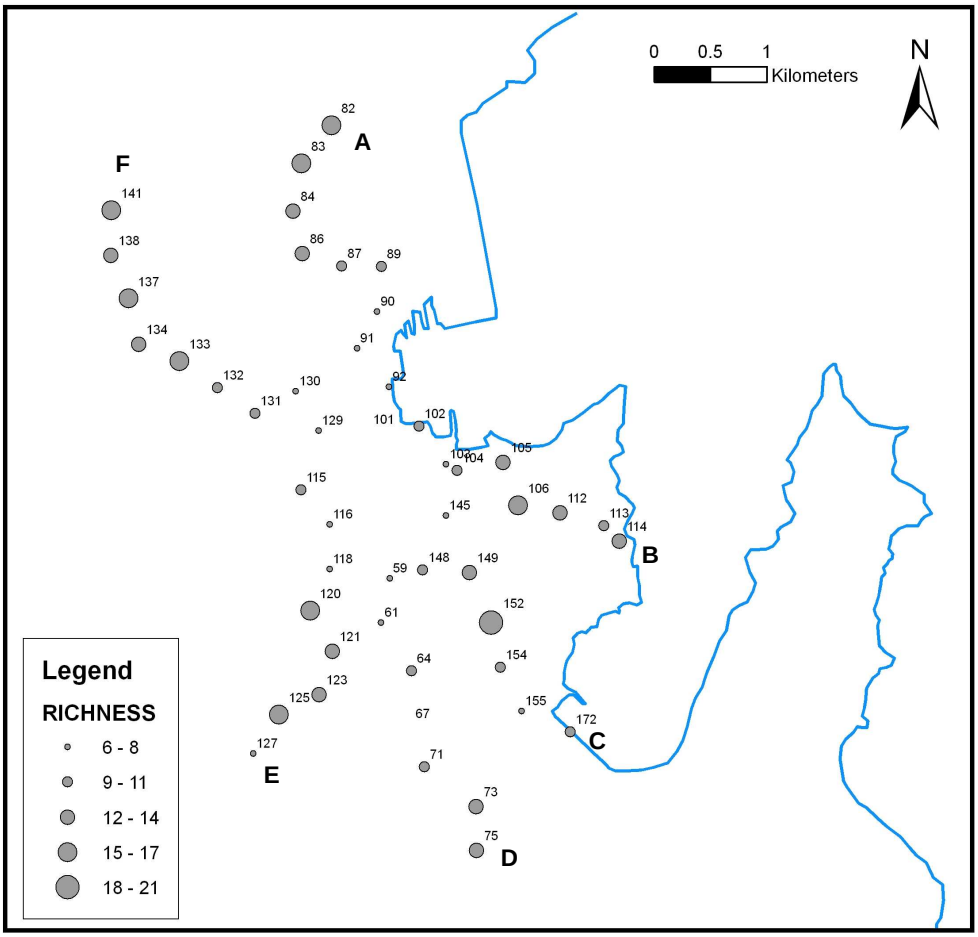

Figure 3.4. Count of avian species richness at the 49 FMBC points along the sampling routes A to F over the period from March 2007 to February 2008. Each FMBC was visited 8 times over this period. The FMBC points are numbered along each of the routes.

Abundance and biomass

There was no relationship between species richness and the total number of individuals present at any point, ($F_{1, 47} = 1.229$, $P = 0.273$) (Figure 3.5). Thus both higher and lower values of richness were recorded when more or fewer individuals were present. For example, 79 individuals of 18 species, 123 individuals of 16 species, or 123 individuals of five species were recorded at different points.

The total biomass of birds as a function of average patch size was not significant ($F_{1, 47} = 0.543$, $P = 0.465$) (Figure 3.6) and showed the majority of points and therefore bird biomass was concentrated in areas with an average patch size between 200 and 2000m^2. Generally, at sites with average patch size larger than 5000 metres fewer counts of birds were recorded. This pattern was also reflected in the scatter plot of total numbers of individuals (Figure 3.7) in which the greater numbers of individuals occupied habitat where average patch size was under 2000m^2. Patches above 5000m^2 had fewer than 100 individuals. An exception that fell outside this trend was seen in both plots, where a higher number (396) of individuals were recorded at a point in a patch of around 2500m^2. This point was identified as the FMBC point 102.

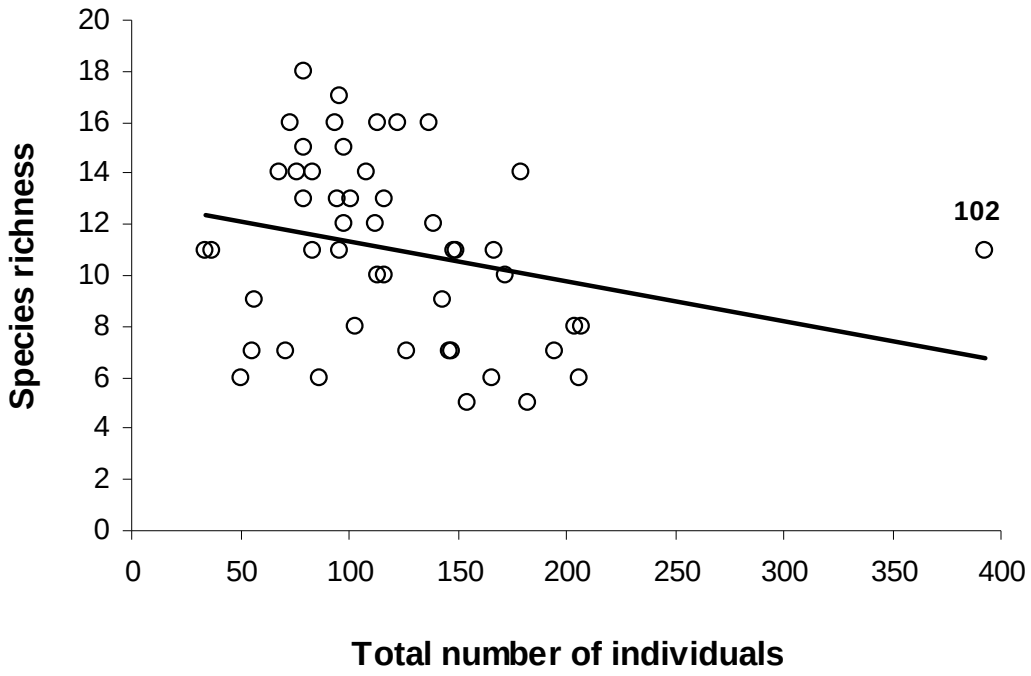

Figure 3.5. Count of species richness at the 49 FMBC stations over the period from March 2007 to February 2008, as a function of total number of individuals in the surrounding 100 metres. The FMBC point 102 is indicated at which a richness of 11 in 393 individuals was recorded.

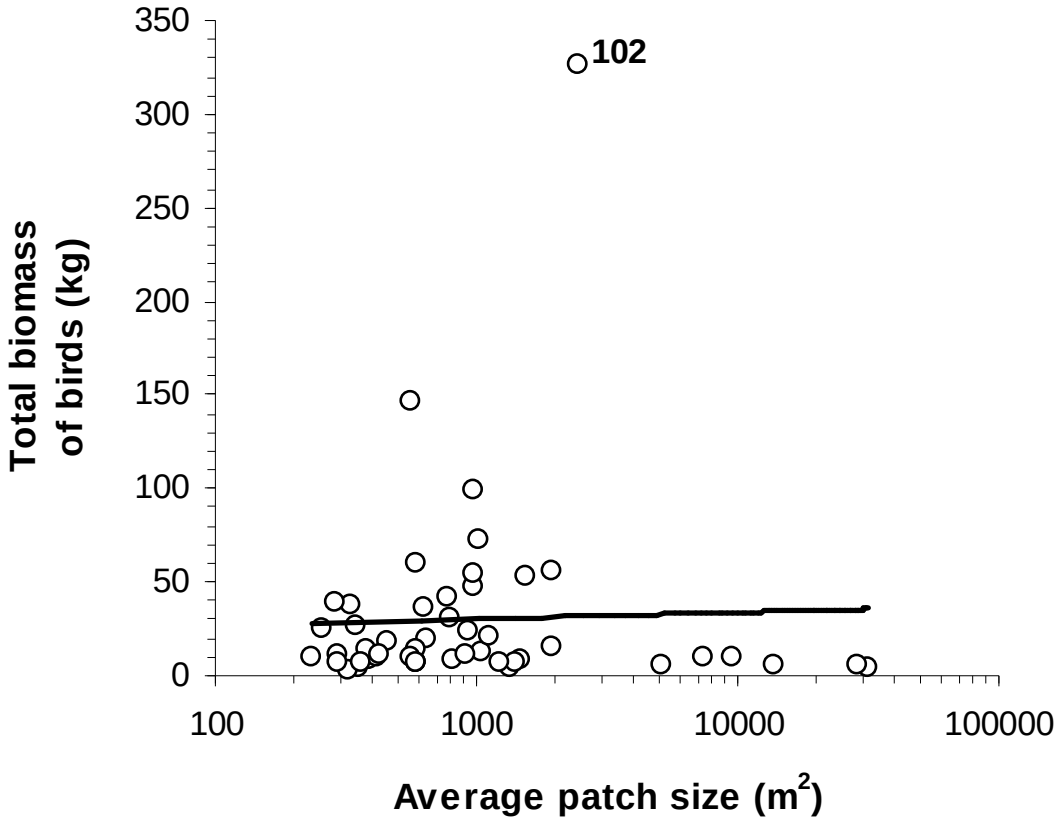

Figure 3.6. Total biomass of all birds seen or heard at the 49 FMBC stations over the period from March 2007 to February 2008, as a function of average habitat patch size in the surrounding 100 meters. A biomass (kg) of 326979 birds in a patch of 2436m^2 was recorded at the FMBC point 102.

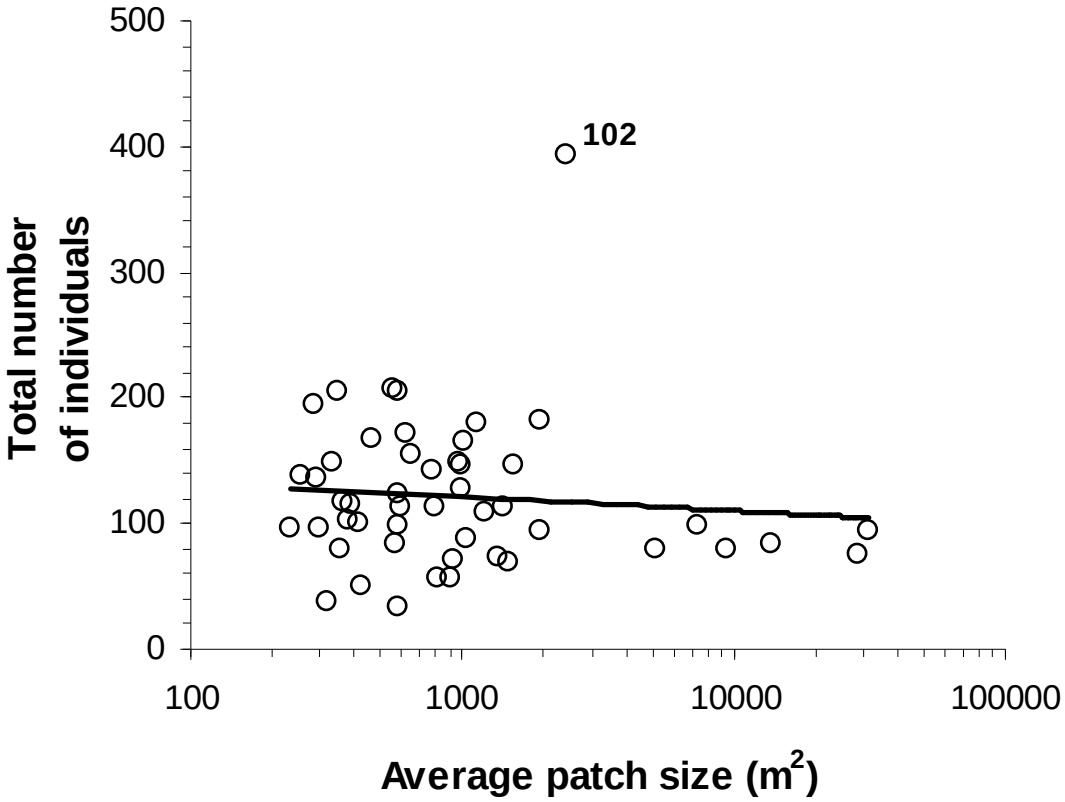

Figure 3.7. Total number of all birds seen or heard at the 49 FMBC stations over the period from March 2007 to February 2008, as a function of average habitat patch size in the surrounding 100 metres. The FMBC point 102 is indicated. It had 393 individuals in a patch of 2436m^2.

Habitat diversity

There was no relationship between species richness and habitat patch diversity ($F_{1, 47} = 0.253$, $P = 0.617$; Figure 3.8). The highest count of habitat types at the FMBC was seven and the lowest was one. Forty of all FMBC sampling points had between four and six habitat types. FMBCs with only one or two habitat types never had low species diversity. Trees made up the larger part of these patches. Other points showed counts of species richness that varied from five species at FMBC 61 and FMBC 67 and up to 18 species at FMBC 152.

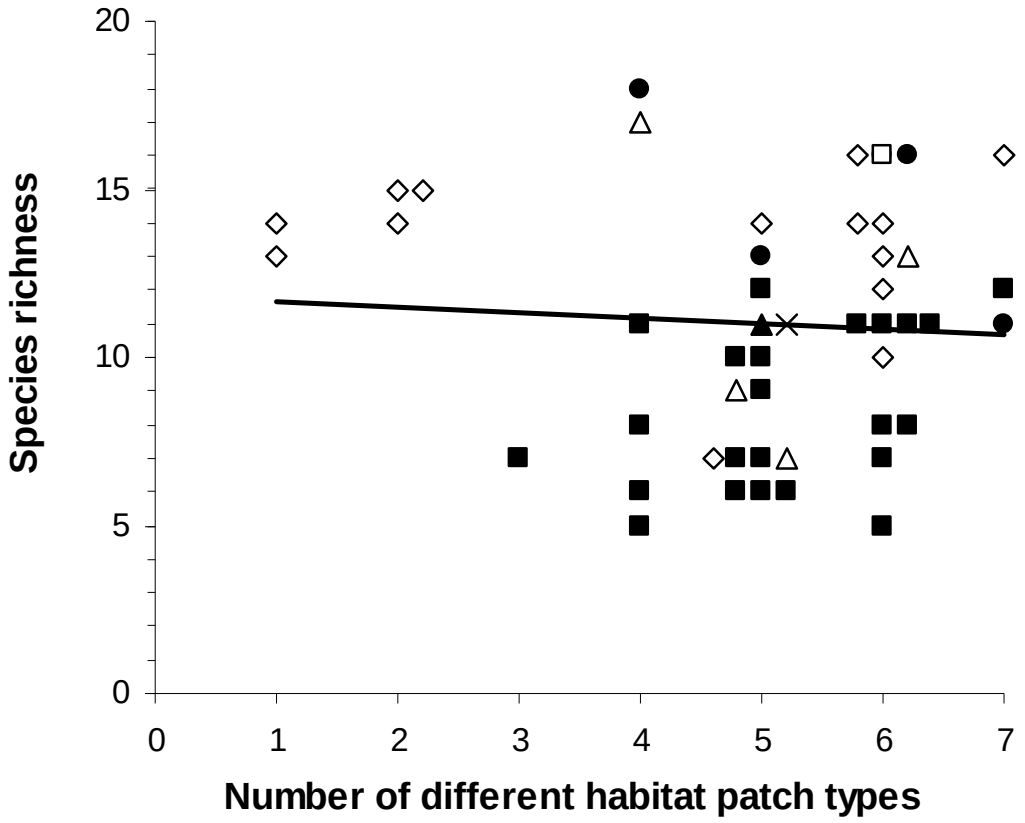

Figure 3.8. Species richness at the 49 FMBC over the period from March 2007 to February 2008, as a function of the number of different habitat types (diversity) at these points. The symbols indicate only the dominant habitat patch types at any point and FMBC sites with overlapping marks of diversity and species richness were separated for display purposes. Symbols for habitat patch types are: trees (◊), trees and lawn (●), sealed surfaces (■), rooftop (▲), lawn (△), ruderal vegetation (□), marine (X). The two different types of sealed surface patches were combined for this analysis.

Average patch size

Average patch size did not influence species richness, although the relationship was nearly significant ($F_{1, 48} = 3.294$, $P = 0.076$; Figure 3.9). In fact, no FMBC's with large patches had low diversity. The effect of average patch size on species richness was less at patch sizes between 300 and 1500 metres. FMBCs in areas where average patch size was large had relatively high species diversity. Conversely smaller patches contained a range in richness, from 5 to 17 species.

The abundance of the five most common species in their preferred habitat was measured against relevant variables of patch structure (1) number of patches, (2) the largest patch and (3) the total area of that patch in the FMBC area. The preferred habitat of blackbird and silvereye was trees (forest), feral pigeon pavement, house sparrow rooftops and starling lawn pasture. A multivariate regression analysis, backward selection procedure was used to interpret results. Weak but mixed relationships were found. For blackbird the model including the number of patches and total patch cover was significant (Table 3.2). The size of the largest patch did not contribute to the relationship. Nevertheless, these relationships were weakly positive (Figure 3.10). None of the variables modified the abundance of silvereye and only the relationship with total patch cover approached significance. Other relationships were negative. The silvereye was equally likely to occur among all patches irrespective of size of largest patch and number of patches (Figure 3.11). The abundance of feral pigeon also appeared to be independent of all variables (Figure 3.12) but again total patch cover approached significance.

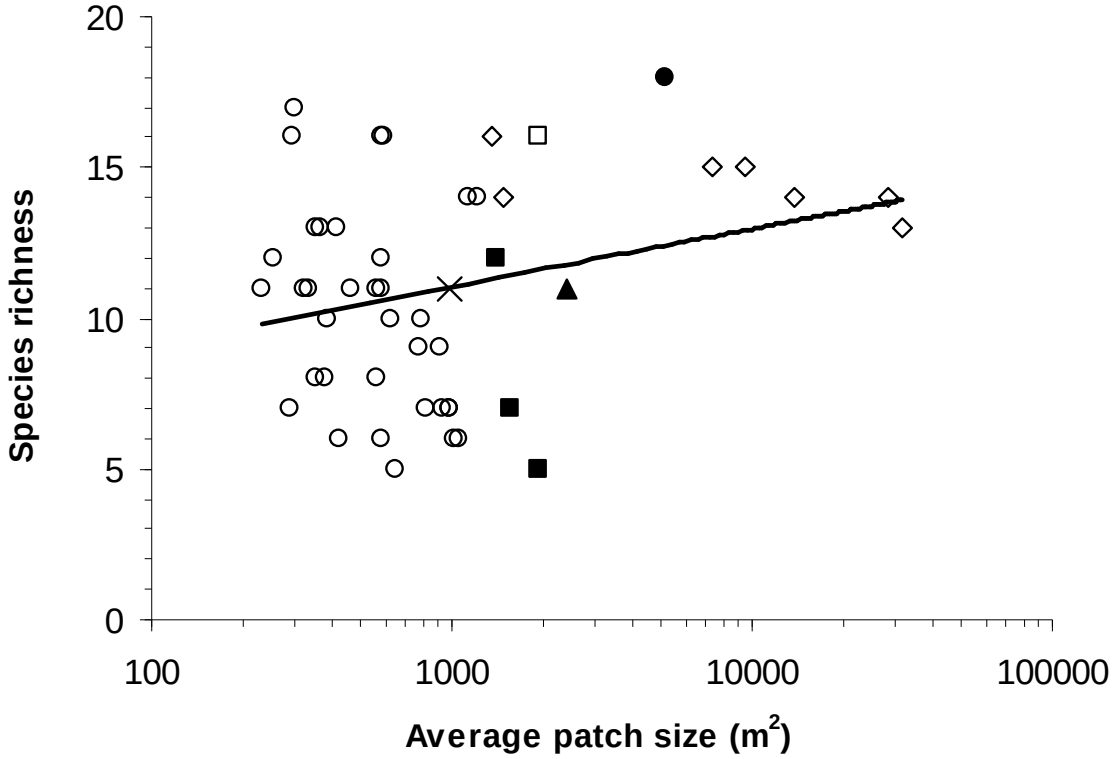

Figure 3.9. Species richness at the 49 FMBC over the period from March 2007 to February 2008, as a function of average habitat size in the surrounding 100 metres. Points of interest have been labeled by the dominant habitat patch type. These points have either relatively high species richness in larger patches or low species richness in smaller patches. Unclassified sites have the symbol (○). See Figure 3.8 for explanation of additional symbols.

Table 3.2. Multivariate regression analysis, backward selection procedure of five species: blackbird, silvereye, feral pigeon and house sparrow and starling in the preferred patch type. Predictor variables were (1) number of patches (2) size of largest patch and (3) total area of the favoured patch cover at FMBC. ANOVA statistics of the most significant model are detailed.

Species	Preferred Habitat	Variables in final model	df	F	P value	Adjusted R^2
Blackbird	Trees	1, 3	2,48	14.994	< 0.001	0.368
Silvereye	Trees	1	1,49	3.214	0.079	0.043
Feral pigeon	Pavements	1	1,48	3.726	0.060	0.054
House sparrow	Rooftop	1, 3	2,47	13.771	<0.001	0.352
Starling	Lawn	-	-	-	-	-

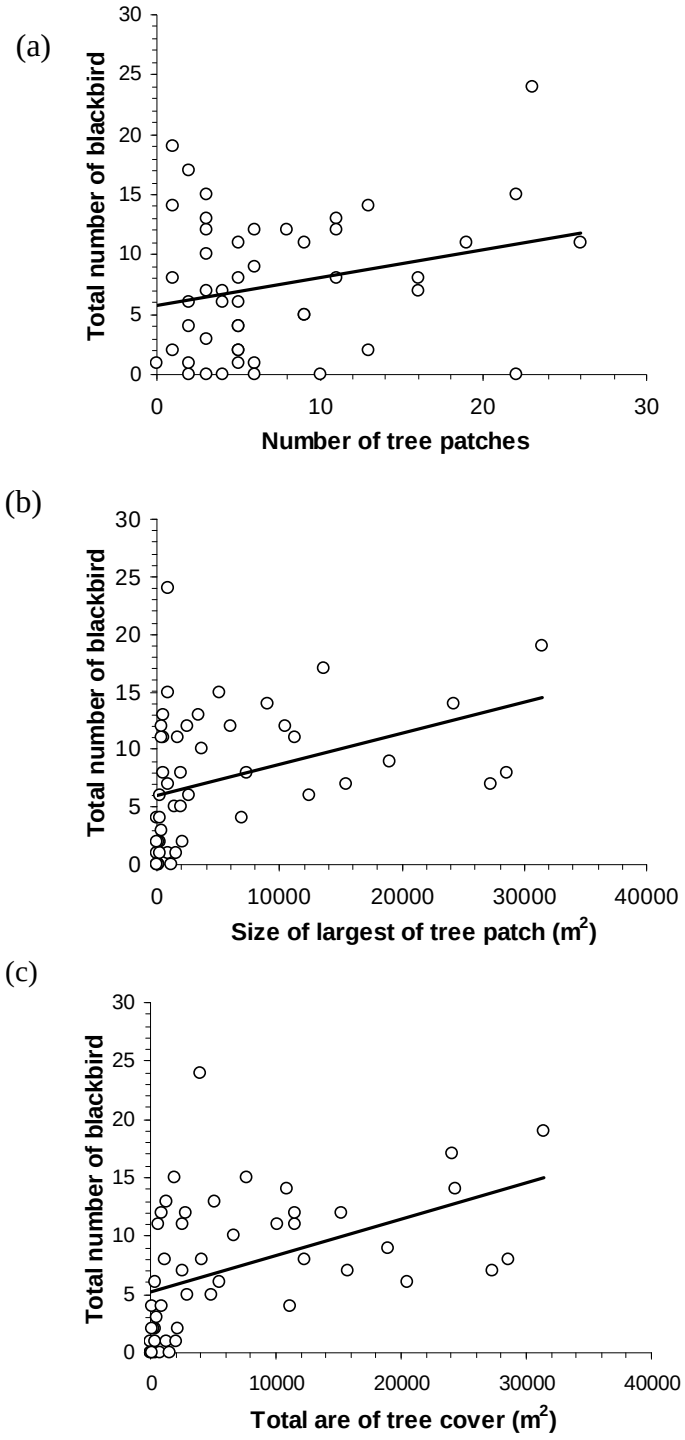

Figure 3.10. The total number of blackbird at the 49 FMBC over the period from March 2007 to February 2008 as a function of its favoured patch type – forest; (a) the number of patches (b) the largest patch size and (c) the total area of tree cover in the surrounding FMBC site. Correlation (r^2) of the trendline is (a) 0.06, (b) 0.150, (c) 0.22.

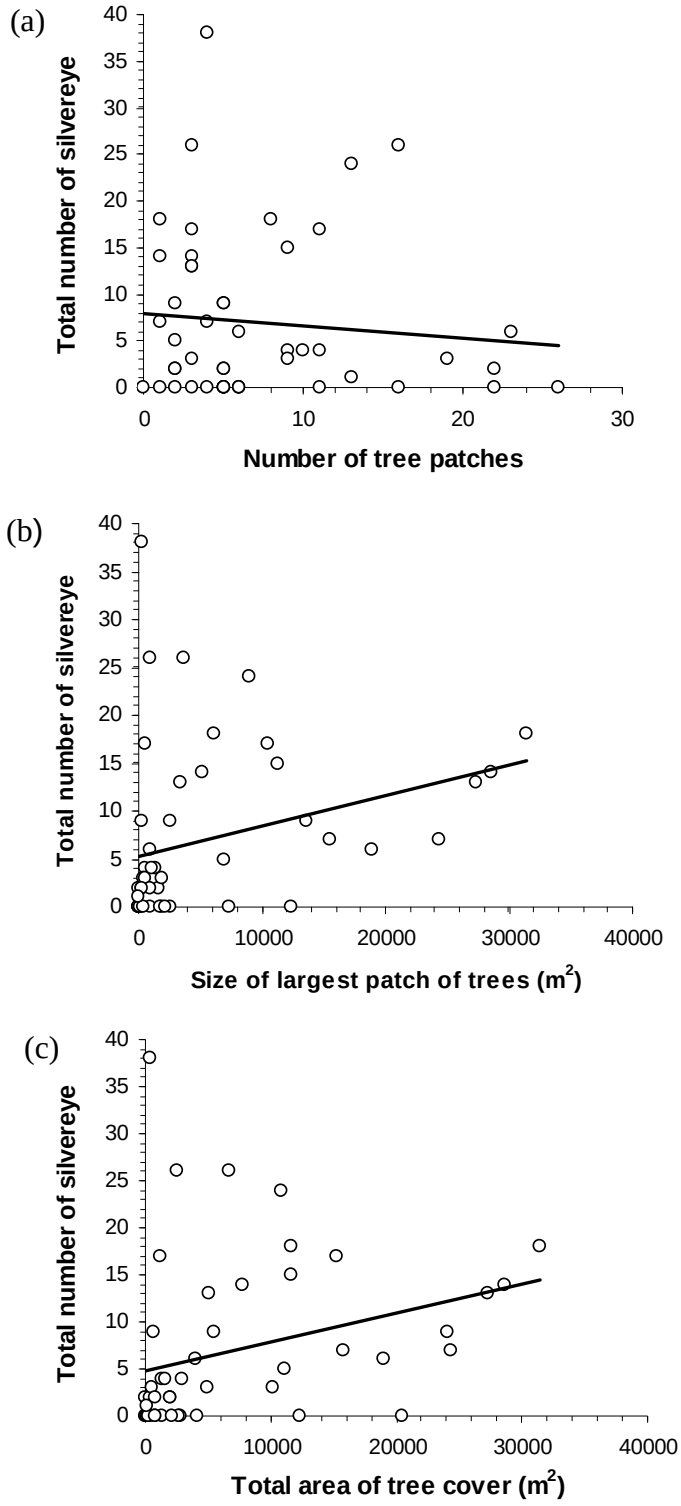

Figure 3.11. The number of silvereye at the 49 FMBC over the period from March 2007 to February 2008, as a function its favoured patch type – forest; (a) the number of patches, (b) the largest patch size and (c) the total area of tree cover in the surrounding FMBC site. Correlation (r^2) of the trendline is (a) 0.009, (b) 0.08, (c) 0.09.

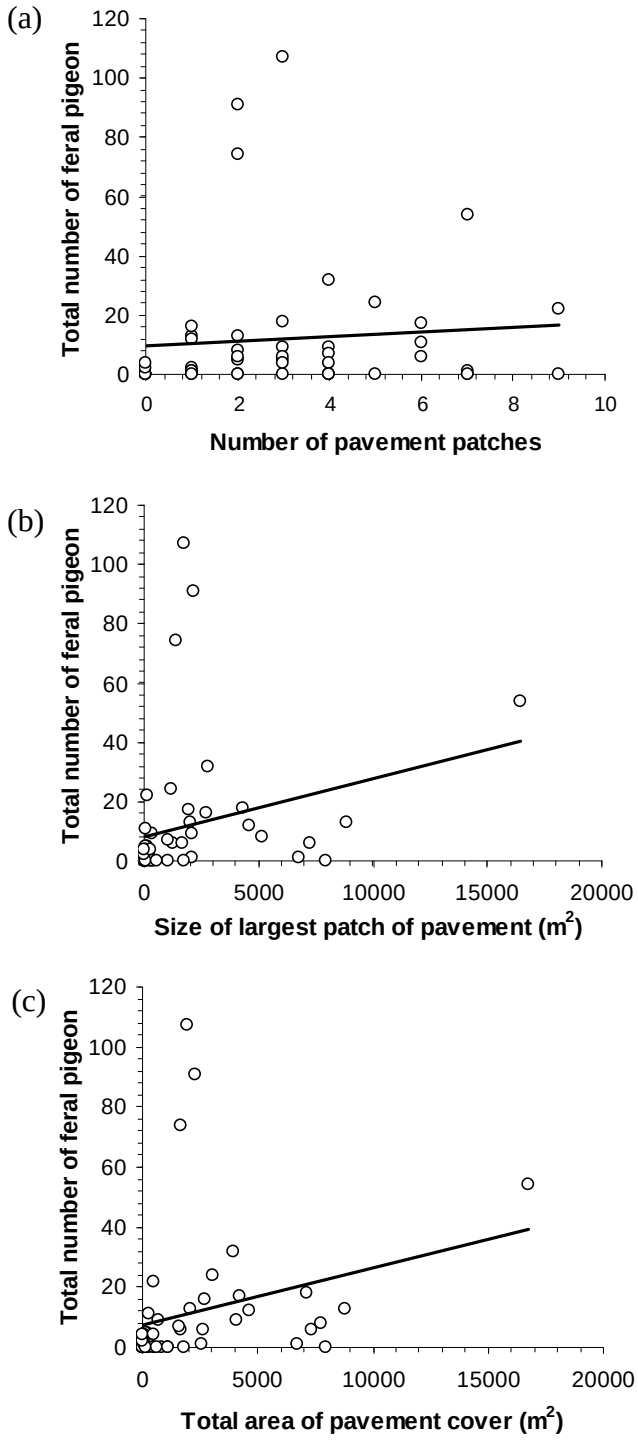

Figure 3.12. The number of feral pigeon at the 49 FMBC stations as a function of its favoured patch type – sealed surface-pavement; (a) the number of patches, (b) the largest patch size and (c) the total area of pavement cover in the surrounding FMBC site. Correlation (r^2) of the trendline is (a) 0.007, (b) 0.06, (c) 0.07.

The number of patches was the most significant in modifying abundance of house sparrow but total area of patch cover approached the significance level. Statistics indicated a negative relationship with size of largest patch, but more strongly positive relationships are evident for the other variables (Figure 3.13). Finally, no relationship among any of these variables and abundance of starling was evident (Figure3.14). A summary of the ANOVA statistics is given in Table 3.2.

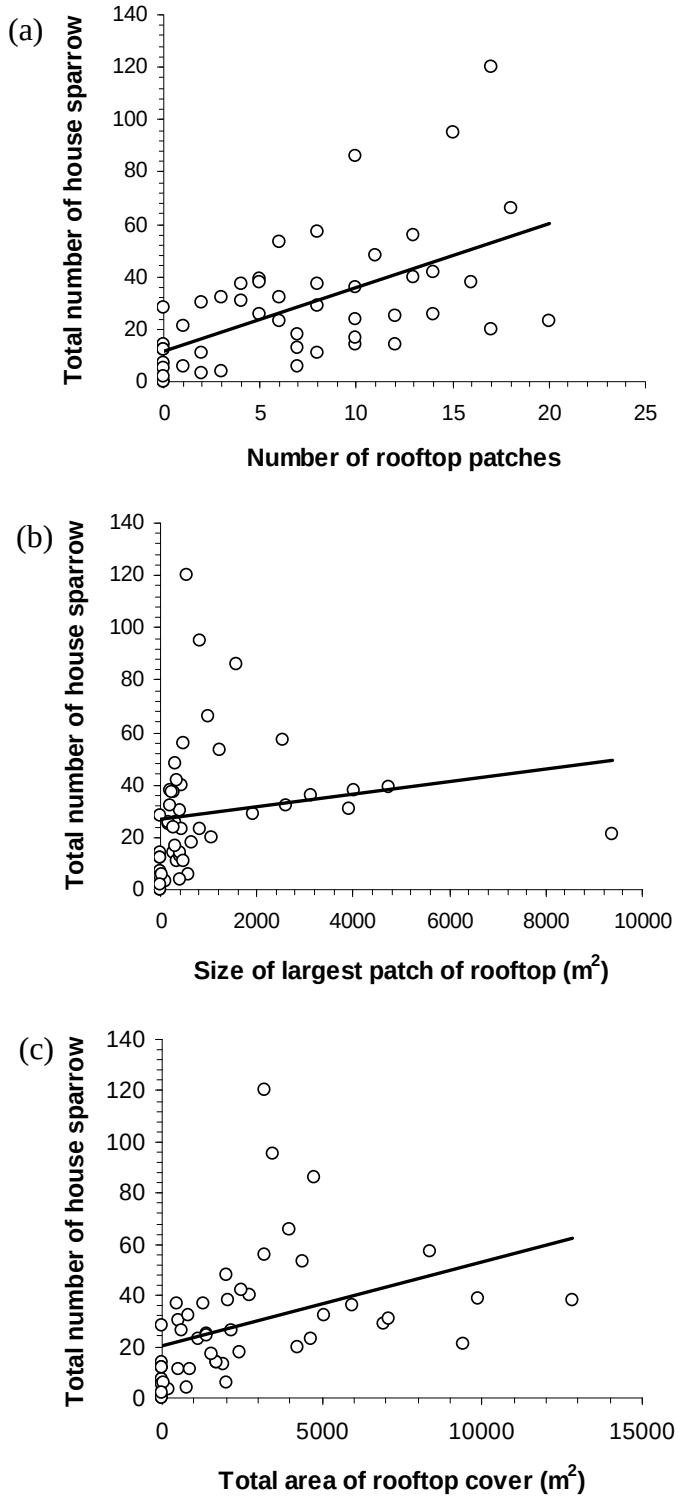

Figure 3.13. The number of house sparrow at the 49 FMBC stations as a function of its favoured patch type – rooftop; (a) the number of patches, (b) the largest patch size and (c) the total area of rooftop cover in the FMBC site. Correlation (r^2) of the trendline is (a) 0.32, (b) 0.03, (c) 0.16.

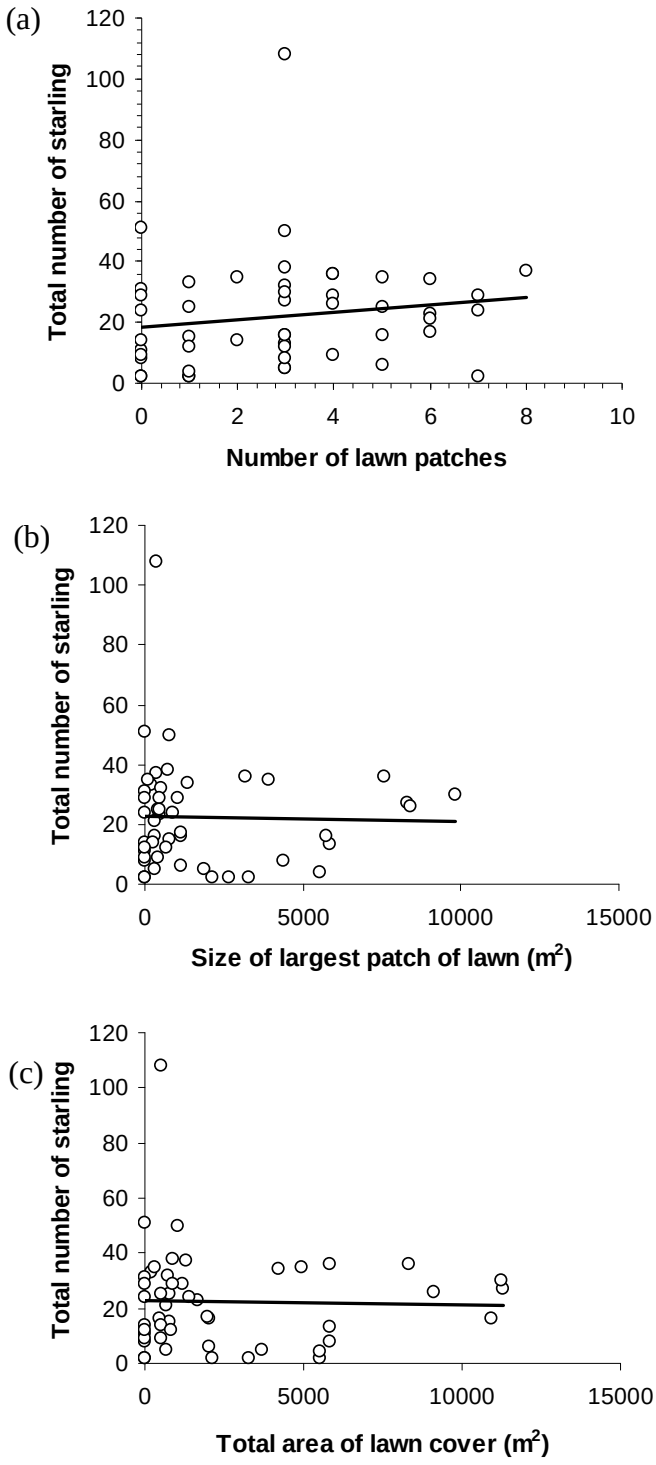

Figure 3.14. Total number of starling at the 49 FMBC over the period from March 2007 to February 2008, as a function of its favoured patch type – lawn; (a) the number of patches (b) the largest patch size and (c) the total area of lawn cover in the FMBC site. Predictor variables (x axis) are not significant for the total number of starlings (y axis).

Discussion

Avian communities in the Wellington urban area were dominated by six common species: house sparrow (*Passer domesticus*), starling (*Sturnus vulgaris*), black-backed gull (*Larus dominicanus*), feral pigeon (*Columba livia*), blackbird (*Turdus merula*) and silvereye (*Zosterops lateralis*). Many more species were present in much lower numbers at fewer sites, and the total numbers of individuals at FMBC did not correlate with species richness. Across the 49 FMBC the six most common species made up 54.5 % of all individuals recorded. Sparrow and starling accounted for 77 % of these birds. Patterns of occupancy for native forest and woodland species mirror the situation along the strip segments (Chapter 2): tui was less abundant but more widespread than silvereye and less common forest species were more restricted by habitat requirements. The spread of grey warbler across the FMBC is roughly similar to greenfinch and dunnock; the wider range of this species may reflect its mating behaviour with permanent occupation of territory throughout the year.

Neither habitat patch diversity nor average patch size influenced species diversity across the community of birds in my study area. Also, both the total number of individuals and total biomass of all birds were independent of average patch size. However, the abundance of some individuals in their favoured patch type did vary in response to patch structure with the strongest relationships seen for blackbird and sparrow.

Species richness and abundance

Species richness in the avian community was not driven by the diversity of habitat patch types. My results suggest only a weak relationship between patch size and species richness with only larger patches maintaining relatively high species richness. Patch

composition at these sites was either trees alone or trees and lawn, and landscape type was either green alone or a mixture of green and both residential landscapes. In green (forest) habitat forest birds made up the bulk of all species recorded. The species present in these larger patches but not occupying smaller patches included bellbird (*Anthornis melanura*), kaka (*Nestor meridionalis*), kingfisher (*Todiramphus sanctus*), morepork (*Ninox novaeseelandiae*), little shag *Phalacrocorax melanoleucos*), eastern rosella (*Platycercus eximius*), whitehead (*Mohoua albicilla*) and yellowhammer (*Emberiza citrinella*). Generally neither abundance nor biomass of birds related to average patch size. It is possible that the higher productivity and increased availability of food that is common in cities and towns allows smaller patches of habitat to support greater numbers of birds, more particularly urban adapted species.

An in depth analysis of patch composition and patch structure for the five common species showed stronger, but still relatively weak or mixed relationships. I postulated that within its preferred patch type a species abundance would increase in relation to patch number, patch size and total area of patch cover at a given point. For blackbird the numbers of patches may be important because of its specialist feeding ecology and breeding requirements. Blackbirds are territorial all year and the site must provide all foraging and nesting opportunities. I speculate that total patch cover is important because the size of the patch is limiting on the resources it can provide. Similarly for house sparrow the number of patches would be important in the breeding season since holding of territory again becomes essential. The abundance of house sparrow in the densely built urban centre is relatively high and territory holders would be rewarded. My results suggest that the abundance of starling is not modified by patch structure – as a true generalist most conditions satisfy its requirements for foraging and survival. I suggest in consideration of all these findings, that fine patch structure within

the urban setting is not a major influence in driving bird biodiversity; rather, birds are responding more to cues at the larger scale of landscape (Chapter 2). More likely, at least for more common birds that are urban-adapted, their habitat needs are non-specific. For example a more generalist pattern of feeding means association with a range of habitat types rather than any one particular type at the local scale (within 50-100 metres). It is also possible that the grain or scale I used to delineate some patches within these local urban sites may have been too fine. Some habitats patches would in fact be too small to be relevant to a range of species because individual trees, flowers or clumps of plants may either not be recognised by a species or not provide sufficient resources to satisfy foragers.

A further question then is if local habitat within the FMBC is not influencing community structure or individual species abundance, does proximity to surrounding landscape have more importance for bird biodiversity? I designed my study in order to examine the effect of the surrounding urbanisation on bird species richness and abundance (Chapter 2). What now transpires is the reverse – how are the surrounding features of landscape, for instance, larger parks and forested areas influencing birds in urban and suburban habitat? Other studies (Hostetler 2001; Melles et al. 2003; Miller et al. 2001) discuss the advantage of using a multi-scale analysis when studying avian community structure in urban areas. For example, an urban study that included the surrounding landscape mosaic (Melles et al. 2003) found more sensitive groups of species associated with both local and landscape level habitat features. They also found and that as forest cover reduced fewer more “urban-adapted” species dominated. To gauge a possible effect of surrounding landscape I looked more closely at the relationship(s) of a species abundance in its favoured patch, and patch composition, (i.e the variables of number of patches, size of largest patch and total area of patch cover) (Figures 3.10 to

3.14). I found that silvereye associated with residential landscapes (mostly detached dwellings) along sampling routes with an abundance of trees and or shrubs, irrespective of these variables. Similarly high numbers of blackbird in smaller patches were concentrated in green and residential landscapes. Feral pigeon showed preponderance for high-rise commercial districts, but sparrow and starling had no definite association with any particular landscape. These findings appear to support the observation that fine scale structure of local habitat (within 50-metres) is less important for these birds than the surrounding features of landscape.

Conclusion

Six species dominated the avian community in urban Wellington and made up the majority of birds. In particular four species, house sparrow, starling, black-backed gull and feral pigeon accounted for more than 60% of individuals. Species richness was highest at FMBC points where abundance was lowest. Biodiversity, abundance and biomass across the community of birds were not driven by either habitat patch diversity or average patch size. However abundance of individual species is influenced by the fine patch structure of its favoured patch type. Some species abundance increased with increase in the number of patches and with the total area covered by the patch. Other species were randomly abundant across all patches irrespective of fine patch structure.

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Chapter 4: Summary and recommendations

The objectives of this study were to determine how biodiversity and abundance of the avian community in urban Wellington changed in relation to the varying levels of urbanisation and, at the local scale, to the fine patch structure of habitat that contributes to the landscape mosaic.

Summary of results

Bird biodiversity changed with landscape type (i.e. classification) but not with the number of landscapes within a site, with decreasing numbers of birds utilising more built landscape. Total avian abundance was independent of landscape classification but individual species were more or less abundant within particular landscape. Species such as house sparrow were more abundant in the breeding season across spring and summer while others like starling were equally abundant all year round. The species ecology modifies and can be used to explain patterns in abundance of species in time and space. Dominant food type, food diversity, dominant landscape and sociality all influenced where a species occurs and its abundance in the urban landscape. Food diversity more markedly influenced species abundance across seasons.

Neither habitat patch diversity nor average patch size related to species richness across the total community of birds. Total biomass and total number of individuals did not increase with patch size and there was also no relationship between increasing numbers of individuals and species richness. A few species accounted for most birds and the greater biomass of birds was concentrated in FMBC's in more built landscapes. Higher numbers of species inhabited less built landscapes more distant from the urban core. Finally, fine

scale patch structure showed only weak or mixed relationships with abundance of individual species within their preferred habitat.

A limitation of this study was that counts of less common species were too low and too highly variable to allow relevant analysis. My analysis of avian community patterns was therefore restricted to the more common species. Increasing the time period of the survey would increase the sample size but would not change the ratio of rare to common species.

A future study design could purposefully seek out and sample the more rare landscapes that in this study had a low sample size. Here I sampled each landscape in proportion to its abundance but two of my dominant landscapes, commercial 1-3 storey and wharf littoral landscapes had small sample sizes. There were only three low storey commercial landscapes and two wharf littoral landscape across my study area.

In synthesising the findings of this study I conclude that: (1) landscape classification correlates positively with avian biodiversity, (2) bird biodiversity in this urban setting is more likely driven by landscape as opposed to local scale habitat and (3) the birds studied showed a closer association with landscape level features and were more likely to be generalists in feeding diversity.

Recommendations

The findings of this study suggest that features of the landscape are important in building avian biodiversity in Wellington. A single recommendation would be to diversify the range of vegetative plantings within the larger parks and reserves surrounding Wellington to target specific species. For example, planting of taller trees provides habitat for kaka, and mixed planting of native and exotic species provide continuous sources of nectar to

attract bellbird. I also recommend diversification of inner city parks away from large areas of uniform cover such as lawn, and the planting of native species as roof gardens. Further, where intensive land development has already occurred protection of less modified, ruderal or re-vegetated habitat from disturbance to allow ecological succession, will both increase plant and animal diversity as well as reduce diversity of non-native species (McKinney 2002)

Future research

Based on the findings of this research, I suggest a further avenue of research: that the model of a species ecology in modifying patterns of abundance within landscape be further developed.

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Appendix 1: Tables of raw data

A summary of species occurrence and abundance at strip transect segments in Wellington. (Raw data used to construct Figure 2.5. Species occupancy of strip-transect segments).

Species and family	Category	Total number of individuals	Number of strip-segments occupied (N =51)	Percent occupancy (%) of strip-segment
Silvereye: Zosteropidae	Native	582	38	74.5
Tui: Meliphagidae	Native	400	40	78.4
Grey warbler: Acanthizidae	Native	98	24	47.1
Fantail: Monarchidae	Native	66	16	31.4
Bellbird: Meliphagidae	Native	41	10	19.6
Kingfisher: Alcedinidae	Native	15	9	17.6
Whitehead: Pachycephalida	Native	8	3	5.9
Kaka: Psittacidae	Native	7	5	9.8
Shining cuckoo: Cuculidae	Native	6	5	9.8
Long-tailed cuckoo: Cuculidae	Native	3	2	3.9
NZ wood pigeon: Columbidae	Native	3	2	3.9
Swallow: Hirundinidae	Native	3	3	5.9
N Z Pipit: Motacillidae	Native	1	1	2.0
Black-backed gull: Laridae	Native	1075	43	84.3
Red-billed gull: Laridae	Native	566	21	41.2

Species and family	Category	Total number of individuals	Number of strip-segments occupied (N =51)	Percent occupancy (%) of strip-segment
Black shag: Phalacrocoracidae	Native	6	4	7.8
Little black shag: Phalacrocoracidae	Native	5	2	3.9
Little shag Phalacrocoracidae	Native	2	2	3.9
Variable oystercatcher: Haematopodidae	Native	2	1	2.0
Paradise shelduck: Anatidae	Native	1	1	2.0
House sparrow: Ploceidae	Introduced	3116	49	96.1
Starling: Sturnidae	Introduced	1881	48	94.1
Feral pigeon: Columbida	Introduced	1001	38	74.5
Blackbird: Muscicapidae	Introduced	781	49	96.1
Greenfinch: Fringillidae	Introduced	154	28	54.9
Goldfinch: Fringillidae	Introduced	146	16	31.4
Mallard: Anatidae	Introduced	185	5	9.8
Dunnock: Prunellidae	Introduced	98	24	47.1
Song thrush: Muscicapidae	Introduced	76	30	58.8
Australian magpie: Cracticidae	Introduced	70	17	33.3
Redpoll: Fringillidae	Introduced	20	5	9.8
Eastern rosella: Psittacidae	Introduced	19	10	19.6
Yellowhammer: Emberizidae	Introduced	15	7	13.7
Rook: Corvidae	Introduced	1	1	2.0

Species and family	Category	Total number of individuals	Number of strip-segments occupied (N =51)	Percent occupancy (%) of strip-segment
Totals		**10966**		

Appendix 2: Tables of raw data

A summary of species occupancy and abundance of five-minute count (FMBC) stations in Wellington. (Raw data used to construct Figure 3.2 Species occupancy of strip-transect segments).

Species and family	Category	Total number of individuals in FMBC	Proportion of FMBC occupied (N = 49)	Percent occupancy (%) of FMBC
Silvereye: Zosteropidae	Native	343	33	67.3
Tui: Meliphagidae	Native	218	38	77.6.
Grey warbler: Acanthizidae	Native	58	22	44.9
Whitehead: Pachycephalida	Native	40	8	16.3
Fantail: Monarchidae	Native	23	18	36.7
Bellbird: Meliphagidae	Native	18	8	16.3
Kaka: Psittacidae	Native	8	4	8.2
Morepork: Strigidae	Native	1	1	2.0
Shining cuckoo: Cuculidae	Native	1	1	2.0
NZ wood pigeon: Columbidae	Native	1	1	2.0
Kingfisher: Alcedinidae	Native	4	4	8.2
Parakeet: Psittacidae	Native	1	1	2.0
Black-backed gull: Laridae	Native	745	42	85.7

Species and family	Category	Total number of individuals in FMBC	Proportion of FMBC occupied (N = 49)	Percent occupancy (%) of FMBC
Red-billed gull: Laridae	Native	241	23	46.9
Black shag: Phalacrocoracidae	Native	1	1	2.0
Little black shag: Phalacrocoracidae	Native	5	3	6.1
Little shag: Phalacrocoracidae	Native	5	5	10.2
Variableoyster catcher: Haematopodidae	Native	2	1	2.0
House sparrow: Ploceidae	Introduced	1427	47	95.9
Starling: Sturnidae	Introduced	1088	49	100.0
Feral pigeon: Columbidae	Introduced	585	32	65.3
Blackbird: Muscicapidae	Introduced	363	43	87.8
Chaffinch: Fringillidae	Introduced	311	38	77.6
Mallard: Anatidae	Introduced	195	3	6.1
Greenfinch: Fringillidae (Carduelinae)	Introduced	77	27	55.1
Dunnock: Prunellidae	Introduced	65	25	51.0
Goldfinch: Fringillidae (Carduelinae)	Introduced	46	12	24.5
Song thrush: Muscicapidae	Introduced	26	18	36.7

Species and family	Category	Total number of individuals in FMBC	Proportion of FMBC occupied (N = 49)	Percent occupancy (%) of FMBC
Redpoll: Fringillidae	Introduced	26	12	24.5
Australian magpie: Cracticidae	Introduced	20	10	20.4
Eastern rosella: Psittacidae	Introduced	8	3	6.1
Yellowhammer: Emberizidae	Introduced	6	4	8.2
Rook: Corvidae	Introduced	1	1	2.0
Totals		**5960**		

Appendix 3: Views of urban Wellington City from Mount Victoria