The effects of urbanisation on the feeding ecology and physiology of Mallards, *Anas platyrhynchos*

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Synopsis

In this thesis, I address the extent of wildlife feeding (of Mallards, *Anas platyrhynchos*) in an urban park, and evaluate whether there are discernible differences in body composition and health between urban and rural Mallards. With an increasingly urban human population, more people are engaging with wildlife at their local parks by feeding. Although similar studies have been conducted exploring the participation rates of wildlife feeding in Australasia, this is the first study to my knowledge that quantitatively explores the degree of anthropogenic food being offered to Mallards through wildlife feeding in an urban park, and the impacts the foods on offer have on the physiology and health of Mallards.

I surveyed wildlife feeding at the Victoria Esplanade pond in Palmerston North, a frequently visited site for urban feeders. I documented the types and amounts of food being given to ducks, and the basic demographic structure of the party (numbers of adults and children) on weekdays and weekends in late summer and early winter 2018. Results showed that feeding activity was highest on weekends, was most often done by 1–2 adults with 1–2 children, and usually consisted of commercial bread, though a wide range of foods was offered. Not unexpectedly, bread offered tended to be of cheaper brands. When food was offered, the large majority of ducks present attempted to eat it, but natural foraging was also present throughout the day. Counts and GPS tracking of two ducks indicate that many birds leave the pond at night, presumably to forage on natural food sources elsewhere.

To determine if living in an urban environment affects the physiology and health of Mallards, I compared the body composition of urban and rural ducks. Reliance on anthropogenic food that is low in fibre and high in carbohydrates could result in birds having smaller digestive organs and higher fat levels, with associated health issues. Instead, I found that urban birds had larger gizzards and caeca, while rural birds had larger flight muscles. These differences may reflect other aspects of the birds' environments and behaviour than anthropogenic feeding. Birds in Victoria Esplanade are known to feed on acorns and palm tree seeds, which likely require a large gizzard, and rural birds probably have higher flight activity than urban birds (resulting in larger flight muscles). Longer caeca in urban birds are unlikely to reflect higher cellulose breakdown needs but could potentially relate to higher immunosurveillance in a high-density pond situation. No other health differences were observed.

Together, these results indicate that Mallard physiology is responsive to local conditions, but at the current level of wildlife feeding there appear to be no major health impacts on individuals.

The study site does, however, have a diverse environment with other food sources (including a nearby river) and impacts could be greater in truly ‘urban-locked’ pond sites.

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Chapter 1: Literature review: The effects of urbanisation on diet and health of wildlife.

Introduction

In the early 1970s, urban ecology, a new sub-discipline of ecology, emerged as an amalgamation of several disciplines exploring the relation of organisms interacting with each other in an urban environment (McDonnell, 2015). With the human population continuing to grow and being expected to reach 9.6 billion by the year 2050 (United Nations, 2017), a large proportion of landscapes are being transformed and converted into urban spaces for humans (Oro et al., 2013; McDonnell, 2015). Consequently, there has been an increase in the need to understand the effects of urbanisation on wildlife living within these changing landscapes (Traut & Hostetler, 2003; Chace & Walsh, 2006).

The effects of urbanisation on avian distributions and diversity have been well studied (Hostetler & Knowles-Yanez, 2003; Amrhein, 2014). It has been found that urbanisation results in a decrease in species richness of native species (van Heezik et al., 2008), as large populations of introduced species displace native species (Garaffa et al., 2009; Wilcoxen et al., 2015). Many native species are displaced by species belonging to the *Anseriformes*, *Columbiformes* and *Passeriformes* orders (Blair, 1996). One of the largest drivers causing communities in urban environments to change is the availability of food through natural food sources or through anthropogenic feeding (Galbraith et al., 2015). However, the direct effects of food availability and diet composition on the health of urban birds have not been well documented, and only recently have studies been conducted to explore these effects (Traut & Hostetler, 2003; Oro et al., 2013). Thus, more studies need to be conducted exploring the impacts on wildlife feeding is having on recipient urban individuals.

Studies have shown that there are both positive and negative aspects to humans feeding urban wildlife. Urban wildlife can have greater breeding population density than rural wildlife of the same species (Chace & Walsh, 2006). Furthermore, urban populations may also have higher survival rates over winter periods (Jones & Reynolds, 2008). While anthropogenic food has allowed for an increase in reproductive success and survival rates in urban wildlife populations, it may also have a negative impact on the wildlife community (Amrhein, 2014). Negative impacts such as changes in behaviour, developing dependency on anthropogenic food supplies, and increased risk of disease are the most commonly cited arguments against the practise, or why more research is needed to be conducted to evaluate these impacts on urban populations (Ottoni et al., 2009; Chapman & Jones, 2011).

Why people feed wildlife

As humans living in urban locations have limited access to nature their perceptions of and interactions with wildlife are rather limited, thus the majority of their interactions are with urban wildlife (Jones, 2011b). The most common deliberate method for humans to interact with urban wildlife is through the provision of supplementary food such as bread and seeds (Jones, 2011a; Wilcoxen et al., 2015). Providing wildlife with supplementary food is a large international industry with an estimation of over five billion USD spent per year in the United States alone (Chapman & Jones, 2009; Jones, 2011a).

Surveys have been conducted internationally asking individuals if they have engaged in active wildlife feeding and, if so, what their reasons were (Jones, 2011a; Galbraith et al., 2014). In New Zealand, an estimated 46.6% (taking into account of non-response bias) of survey recipients stated that their household had taken part in wildlife feeding (Galbraith et al., 2014). Furthermore, it was found that bread was the most commonly provided food to wildlife, with 88.1% of household reporting that bread was the biggest component of food supplies they offered. By reviewing the total number of households, and the quantity of bread supplied in New Zealand, Galbraith et al. (2014) estimated that 5.1 million loaves of bread were being provided to wildlife per year. As to reasons why people feed wildlife, many do it for ethical and moral reasons (Jones, 2011a), including feeding wildlife to compensate for the destructive effect humans have had on their natural environment. Wildlife feeding is becoming so prevalent in some areas that local authorities are installing signs to deter the activity (Ballantyne & Hughes, 2006), but the practice continues to grow (Amrhein, 2014). As research in urban settings continues to grow, so does our understanding of how urban diets affect the well-being of our urban wildlife. Greater insight can be used to encourage the public to make better feeding practises to minimise some negative effects (e.g. spreading of disease) may be mitigated (Wilcoxen et al., 2015).

Urban diets and body mass

The most visually noticeable effect of supplementary feeding on the well-being of urban wildlife has been increased body mass (Amrhein, 2014). Australian Magpies (*Gymnorhina tibicen*) have been observed gaining body mass in response to supplementary feeding of anthropogenic foods. Ishigame et al. (2006) fed fledged first-year Australian Magpies with no history of feeding on anthropogenic foods a combination of high energy foods. Forty-eight hours after eating the offered anthropogenic food, a 3.95% increase in average body mass was observed. Additionally, blood plasma cholesterol was in levels of excess above the known normal ranges of Magpies. The full effects of weight gain and high cholesterol in the short-term for birds are not fully understood (Ishigame et al., 2006).

Although wildlife feeding traditionally has been a winter activity to assist malnourished birds during harsh Northern Hemisphere winters, this is no longer the case with supplementary feeding occurring all year round globally (Jones & Reynolds, 2008). As anthropogenic foods are typically high in carbohydrates (i.e., have high levels of energy) and are readily available (i.e., low effort costs for foraging), anthropogenic foods yield large energy returns for wildlife (Galbraith et al., 2015); this may result in increased body mass in the form of fat deposits (Jensen et al., 1976). Long-term increases in body mass will result in individuals becoming obese, and in turn, potentially the development of fatty liver and heart disease (Ritchie et al., 1994).

Interestingly, not all bird species develop heavier body mass in urban habitats (Amrhein, 2014). Rural House Sparrows (*Passer domesticus*) have larger body masses and overall better condition than individuals living in urban habitats (Liker et al., 2008). As poor body condition and low body weight can affect moulting of feathers and compromise immune systems, having fat reserves produced from anthropogenic foods can be beneficial for a species (Dabbert et al., 1996).

Many urban species are opportunistic feeders and their diet reflects food availability in their environment (Kleyheeg et al., 2016). Therefore, differences between the urban and rural diet are expected (Taylor et al., 2012; Amrhein, 2014). For comparisons to be drawn on the effect of anthropogenic food on an individual’s diet, we must first understand the dietary requirements of that species and the nutritional values of anthropogenic foods (Ottoni et al., 2009). Although many studies have been conducted looking at the diet of wildlife, the focus has almost entirely been on rural wildlife (Chapman & Jones, 2009; Ottoni et al., 2009). Observational and energetics studies of diet have only been routinely performed on species that are endemic or endangered (McNab, 2003), but most species found in New Zealand urban habitats are introduced species and are not endangered. However, animals raised in captivity could potentially be used as a base model for wildlife as they are fed an unnatural diet (Moore & Battley, 2006), have minimal energy expenditure (McNab, 2003), and the food intake and excreta of an animal can be monitored more reliably than in the field (Sugden et al., 1981). Furthermore, observational field studies yield inconclusive results as they only consider what an animal has ingested, rather than what has been digested and absorbed by the body as an energy source (Ottoni et al., 2009; Callicutt et al., 2011).

Monotypic diets

The main foods humans provide wildlife in New Zealand are bread, fruits and seeds (Galbraith et al., 2014). If wildlife only forage on anthropogenic food their diet will lack essential nutrients. Monotypic diets have shown to lack essential nutrients and often fail to provide individuals with their basal metabolic needs. Mallards (*Anas platyrhynchos*) fed a monotypic diet of either corn or soybeans exhibited a substantial decrease in body weight during their respective trials (Miller, 1975; Loesch & Kaminski, 1989). This is most likely due to the diet lacking some nutrition requirements, although, soybeans do contain trypsin inhibitors that suppress appetite that may contribute to the weight loss of the birds (Dabbert & Martin, 1994).

Monotypic diets may also lack certain essential amino acids, minerals and vitamins (Dabbert & Martin, 1994). Nutritional deficiencies have a profound effect on body condition, with individuals potentially losing bodyweight. Wild Mallards maintain nutritional balance by increasing the dietary intake of other food sources in their habitat (Dabbert et al., 1996). By increasing the intake of other food sources, they increase the consumption of foods that may contain the lacking vitamins, minerals and essential amino acids, thus restoring any nutritional imbalance (Dabbert & Martin, 1994).

Given that urban landscapes have been altered to human needs and as anthropogenic foods are absent in the wild, there is a difference in food availability between urban and rural areas (Chace & Walsh, 2006; Amrhein, 2014). Changes in food availability will affect the total quantity of carbohydrates, fats and proteins that individuals ingest (Kohl et al., 2017). Animals that are fed an unnatural diet may potentially develop a reduced ability to digest natural foods (Champagnon et al., 2011). However, birds have highly phenotypically flexible digestive tracts that respond to dietary composition and nutritional value (Champagnon et al., 2011). It is hypothesised that having a gastrointestinal tract that is adaptable to food availability is advantageous as it ensures the optimal digestion of nutrients (McWhorter et al., 2009). Organs that have been found to change in response to food availability and intake are the gizzard, small intestine and liver (Battley & Piersma, 2005).

Plasticity of the digestive system

The gizzard is a muscular organ that is used to mechanically break down food into smaller morsels (Moore, 1998a; Battley & Piersma, 2005). The thickness of the gizzard muscle wall corresponds to the structural integrity of the food source (Moore, 1998a). Ingested plant materials such as grasses are high in fibre and require great mechanical forces to break the cellular matrix (Moore, 1998b). It is for this reason that herbivorous birds have thicker gizzard walls in relation to body size than their omnivorous or carnivorous counterparts (Moore, 1998a). However, some carnivorous birds such as Red Knots (*Calidris canutus*) have large gizzards to break the shells of shellfish in their diet (Dekinga et al., 2001), thus food hardness has an impact on gizzard size as well. Therefore, I predict that the gizzards of omnivorous urban birds will be smaller than those of rural birds as anthropogenic foods are relatively low in fibre content. However, captive Brown Teal (*Anas chlorotis*) fed a soft, low-fibre pellet-based diet had no difference in gizzard size when compared to wild Brown Teal that forage upon hard-shelled molluscs and vegetation (Moore & Battley, 2006).

Food quantity and quality also affect the gastrointestinal length (Miller, 1975; Karasov, 1996). For their body size, birds eat more than mammals but have a shorter gastrointestinal tract (McWhorter et al., 2009). Despite this, birds are just as efficient as mammals at digesting foods as their digestive tract is highly modified for extracting the maximum amount of nutrients (Karasov, 1996; McWhorter et al., 2009).

As the development of longer digestive tracts has high metabolic costs, it is only beneficial to have a longer digestive tract to maximise the yield of metabolisable energy from poor-quality foods (Miller, 1976). Birds with a herbivorous diet (i.e., high fibre diet) will have longer gut lengths than carnivorous birds (Kehoe et al., 1988; Clench & Mathias, 1995). Interestingly, omnivorous species have a relativity longer intestine than herbivorous species suggesting that gut length is determined by dietary diversity than dietary fibre intake (Kehoe et al., 1988).

Food quantity has also been shown to influence liver weight, with liver size increasing in proportion to food intake (McWilliams & Karasov, 2005). As the liver increases in size, so does its capacity to convert food into metabolic energy (McWilliams & Karasov, 2005). Although experiments exploring liver weight change in response to changes in food availability and environmental temperature have been conducted, there is a paucity of research conducted on the effects of food quality on organ size (Kehoe et al., 1988). One study, however, found that high carbohydrate diets resulted in a build-up of fatty deposits in the liver (Jensen et al., 1976), which can have detrimental health effects such fatty liver disease (Zaefarian et al., 2019).

Disease in urban species

Diet plays a pivotal role in avian health as it can affect the immunity system of an individual. Inadequate diets will result in individuals losing body mass as their fat and muscle stores will be used to meet basal metabolic needs (Klasing, 1998). Diets not only have to meet metabolic needs but also need to provide sufficient quantities of essential amino acids and vitamins. Vitamin E is essential for the immune system development and function, with deficiencies leading to cell membrane dysfunctions that result in the cells being more prone to infection, and therefore increases the chance individuals will become diseased (Orosz, 2014). Additionally, if urban birds live in highly dense populations and have a compromised immune system due to their lifestyles, the spread of disease and parasites would be more prevalent in these urban populations, which will have further impacts on their health. Little is known about the effects of anthropogenic foods on the immune system of urban wildlife (Callicutt et al., 2011). A better understanding of the effects of urbanisation on avian immunity is essential for preventing disease outbreaks such as avian botulism (Wobeser, 1997).

Avian botulism is the most significant disease for migrating birds globally and has been linked to human-caused algal blooms in waterways (Thomas et al., 2007; Smith et al., 2015; Staley &

Bonneaud, 2015). Supplementary feeding of wildlife has resulted in high densities of waterfowl around urban waterways, creating conditions that favour algae growth (Murphy et al., 2000; Jones, 2011b). The infection is caused by the bacterium *Clostridium botulinum*, which produces neurotoxins that are ingested by the animal (Wobeser, 1997). There are at least seven neurotoxins produced by *C. botulinum*, but the type C1 toxin is responsible for the most botulism outbreaks in birds (Thomas et al., 2007). The toxins inhibit the release of the neurotransmitter acetylcholine; as acetylcholine is the primary neurotransmitter in the neuromuscular junctions, the botulism toxins cause the birds to experience acute levels of paralysis (Samour, 2008). *Clostridium botulinum* can be present in the soils and sediment for many years (Espelund & Klaveness, 2014), as waterfowl are being attracted to infected sites by supplementary feedings, more individuals will come into contact with the pathogen and will spread it to other water bodies as they migrate. Appropriate management of urban bird populations is vital to minimising the prevalence and transmittance of avian botulism.

A well-balanced diet is also required to prevent metabolic diseases in urban animals. Metabolic bone diseases such as angel wing are commonly observed in captive-reared birds and birds in urban habitats (Francis et al., 1967). Samour (2008) defines the angel wing condition as “the lateral rotation of the distal wing in young growing birds”. Factors such as high levels of protein intake increase the growth rate of feathers to a point where feather weight becomes greater than the bone structure can support, thus resulting in the distal wing rotating (Ritchie et al., 1994; Zsivanovits et al., 2006). Angel wing greatly impairs mobility and limits foraging ability, and as such it is often associated with a loss of body mass as metabolic intake cannot be met (Samour, 2008). Metabolic diseases such as angel wing are an example of why there needs to be an increase in research examining the effect that urban diets are having on the health and well-being of urban wildlife to minimise the impact humans are having on the welfare of individuals live in urban habitats.

Dependence on anthropogenic food

Aside from diet affecting the physical characteristics of urban wildlife, supplementary feeding may alter the foraging behaviours of urban wildlife (Jones, 2011a). Large quantities of anthropogenic foods are being distributed in urban wildlife habitats regularly (Ishigame & Baxter, 2007). As wildlife become accustomed to food resources being readily available to them, natural foraging behaviours may not be utilised and therefore may eventually be lost altogether (Jones & Reynolds, 2008). The loss of foraging skills will become problematic if humans stop providing anthropogenic foods, since the urban wildlife may become reliant on food being supplied (Ottoni et al., 2009; Chapman & Jones, 2011). In the event of anthropogenic food supplies being limited, urban wildlife will need to actively forage for their own food again. If individuals have lost their foraging skills, there is the potential that these individuals will fail to meet energy intake needs and will become malnourished (Chapman & Jones, 2011).

There is increasing evidence that urban wildlife are not dependant on anthropogenic food and that food provision through wildlife feeding only makes up part of their overall diet (Jones, 2018). O'Leary and Jones (2006) found that the Australian Magpie diet consisted predominantly of natural foods despite the presence of anthropogenic foods. Furthermore, it has been observed that anthropogenic food dependency is not present in some waterfowl populations. Chapman and Jones (2011) found that the duration of foraging behaviour of Pacific Black Duck (*Anas superciliosa*) and other unspecified domestic duck species did not alter in the presence of anthropogenic food. Additionally, waterfowl spent a greater proportion of their time foraging for natural food resources instead of foraging upon human-provided bread distributed into the waters (Chapman & Jones, 2011).

Conclusion

As the human population continues to grow more land will be converted into urban habitats, increasing the need to understand urban ecology. Although population densities and species richness of wildlife have been well studied, the effect urbanisation has on the diet of urban wildlife has not. There is a general trend that urban wildlife has larger body masses than their rural conspecifics. Additionally, if urban wildlife only forages on the food offered to them by humans, they could potentially have a monotypic diet. Monotypic diets have been shown to not be fully balanced and lack some of the essential nutrients and energy requirements. A well-balanced diet is needed to maintain body mass and condition as well as supporting a strong immune system. However, there is also evidence to suggest that birds will adjust their digestive system in response to food quality and quantity in urban settings, resulting in individuals becoming well-adapted to local conditions. Whilst reviewing the literature, many concerns have been raised about the health risks associated with wildlife living in urban habitats. Between poor diet and the potentially sedentary lifestyle, it would be expected that urban wildlife would develop excessive fat deposition throughout their bodies which could lead to the development of fatty liver disease.

Thesis aims and objectives

The main objectives of this study are to document the nature and extent of wildlife feeding at the Victoria Esplanade, Palmerston North, New Zealand, and the possible impacts anthropogenic food is having on Mallards that frequent the park. From the information obtained from this study, I hope to obtain a greater understanding of the dynamics of wildlife feeding from both the human aspect and the wildlife aspect. From the human side, I was interested in knowing how much food, and of what type is being offered, how long people are engaged in this activity and when wildlife feeding is most prevalent. From the bird perspective, I am interested in how Mallards respond to anthropogenic food, how they utilise their environment and if the differences in diet and lifestyle of urban and rural Mallards have an impact on their physiology.

Study species: Mallards as a model

The Mallard was selected as the study case species as they are commonly found species in both rural and urban settings globally (Sugden, 1971; Kaminski & Essig, 1992; Chapman & Jones, 2011) and a great deal of research has been conducted of Mallards in captivity (Dabbert & Martin, 1994). Additionally, natural foraging behaviours and the plasticity of their digestive tract is well-known trials (Miller, 1975; Loesch & Kaminski, 1989). By reviewing the diet of urban Mallards and the effect it has on their body condition and health a greater understanding of urbanisation dietary effects of Mallards within the Manawatu region will be obtained.

Mallards are opportunistic omnivores that eat a diverse array of food types (Olsen et al., 2011); this diverse diet has allowed them to a distribute globally (Miller, 1975; Champagnon et al., 2011). Furthermore, Mallards have high levels of plasticity in their digestive tract as their gizzard and small intestine change rapidly (i.e., a few days) in response to food changes (Kleyheeg et al., 2016). Therefore, if urban diets differ greatly to that of the rural diet, it would be expected that the digestive tract will adapt to the local conditions.

As a large proportion (65%) of a rural Mallard's diet consists of plant-like material such as seeds (Dabbert & Martin, 2000), these individuals need strong gizzards to crack open seeds or these will just pass through the digestive tract and no nutrition will be gained (Brochet et al., 2009). Having a diet that mainly consists of plant material, a rural Mallard's caecum is expected to be elongated to achieve maximum digestion efficiency of cellulose (Clench & Mathias, 1995). In contrast, urban Mallards that are fed a diet that is low in fibre and is relatively soft would be expected to have smaller gizzards and caeca than those of rural Mallards (Moore & Battley, 2006).

Mallards are therefore an excellent candidate for a study of urban wildlife feeding, as they are common, accessible, enthusiastic consumers of human handouts with a readily available rural population available for comparison (hunted ducks).

Thesis outline and plan

Each chapter is written as a stand-alone chapter, thus there may be some repetition between the chapters. For each chapter, I did the majority of the work, planned and carried out the research, and analysed and wrote up the results. My supervisors were Phil Battley and Brett Gartrell of Massey University.

Chapter 2: Anthropogenic feeding of urban Mallards: a case study in Palmerston North, New Zealand.

Chapter two investigated the prevalence of anthropogenic feeding to Mallards at the Victoria Esplanade, Palmerston North, New Zealand. By observing human behaviour of wildlife feeding across four months, insight into the practice at this location was obtained. I documented the types and amounts of food being given to ducks, and the basic demographic structure of the party (numbers of adults and children) on weekdays and weekends in late summer and early winter 2018. Additionally, observations of Mallards were also made across the same period to explored how Mallards capitalised on the influx of food and how they used the surrounding area to forage for food through behavioural observations and GPS tracking.

The main finding of wildlife feeding occurring at the Victoria Esplanade was that it is primarily a recreational activity for families. Results showed that feeding activity was highest on weekends, was most often done by 1–2 adults with 1–2 children, and usually consisted of commercial bread, which tended to be cheaper brands, though a wide range of foods was offered. Additionally, foods obtained through wildlife feeding only made up part of the urban Mallard's diet as individuals were observed foraging on naturally occurring foods even in the presence of wildlife feeding. Furthermore, the level of wildlife feeding observed was of inadequate quantity of anthropogenic food such that Mallards would not meet their metabolic needs if they only foraged upon foods.

Chapter 3: Differences in body composition between urban and rural Mallards.

In chapter three the primary focus was to assess if living in an urban environment affects the physiology and health of Mallards. This was achieved by making comparisons of gross morphological differences in body composition, and other health-associated aspects between Mallards in an urban environment with high levels of feeding by humans, and Mallards in rural habitats. Reliance on anthropogenic food that is low in fibre and high in carbohydrates could result in birds having smaller digestive organs and higher fat levels, with associated health issues.

Some significant differences were found between the groups, but in the opposite direction to predictions. I found that urban birds had larger gizzards and caeca, while rural birds had larger flight muscles. These differences may reflect other aspects of the birds' environments and behaviour than anthropogenic feeding. Birds in Victoria Esplanade are known to feed on acorns and palm tree seeds, which likely require a large gizzard, and rural birds probably have higher flight activity than urban birds (resulting in larger flight muscles). Urban birds had larger, rather than smaller, gizzards and caeca, and there was no difference in their fat stores compared to rural birds. Overall, while urban and rural environments affect Mallard physiology, no obvious concerns for wildlife health were found in this study.

Chapter 4: Overall discussion and conclusions

From the results of these studies, it appears that the level of wildlife feeding occurring at the Victoria Esplanade is not having a detrimental effect on the gastrointestinal health of the resident population of Mallards. I found strong evidence to suggest that Mallards at the Victoria Esplanade are not entirely reliant on anthropogenic food to meet their metabolic needs. As the Victoria Esplanade has a diverse set of habitats near the urban fringe, the level of wildlife feeding may be offset by the quantity of naturally occurring food available for Mallards and thus does not generate discernible ill effects upon them.

Chapter 2

Anthropogenic feeding of urban Mallards, *Anas platyrhynchos*: a case study in Palmerston North, New Zealand

Chapter 2: Anthropogenic feeding of urban Mallards *Anas platyrhynchos*: a case study in Palmerston North, New Zealand.

Abstract

*Feeding of wildlife is a pastime enjoyed by many individuals. However, few studies exploring the prevalence of the practice at one set location have been conducted. In this case study, I assessed the level of wildlife feeding of anthropogenic foods to the Mallard (*Anas platyrhynchos*) population at the Victoria Esplanade in Palmerston North, New Zealand. This was achieved by weighing the food people were offering to the Mallards prior to feeding across a four-month period. Additionally, I explored how Mallards foraging behaviour changed in response to the influx of anthropogenic food and how they used the surrounding area to forage for food through behavioural observations and GPS tracking. This study showed that the occurrence of wildlife feeding at the Victoria Esplanade was greatest during the weekend and that the overall that anthropogenic food offered to the Mallards only made up part of their total food consumption. Furthermore, my results support that wildlife feeding is now a recreational activity for families as opposed to its origins of supplementary food for animals through harsh winters.*

Introduction

Wildlife feeding is the most common deliberate interaction that many humans have with wildlife and has been a pastime enjoyed by many generations (Chapman & Jones, 2009; Cox & Gaston, 2016). Although wildlife feeding has traditionally been conducted to assist malnourished birds during harsh Northern Hemisphere winters, this is no longer the case with supplemental feeding occurring year-round globally (Jones, 2018). Today, wildlife feeding of birds is a multibillion-dollar industry with US$3.5 billion spent each year in the United States alone (Jones & Reynolds, 2008). In New Zealand, it has been estimated that 46.6% of households engage in wildlife feeding (Galbraith et al., 2014). Bread is the most commonly provided food, with 88.1% of household reporting that bread was the biggest component of food they offered. It is estimated that 5.1 million loaves of bread per annum were being provided for wildlife feeding in New Zealand (Galbraith et al., 2014).

As more studies are conducted into the possible effects of supplementary feeding on wildlife, it has been suggested that it may be doing more harm than good (Orams, 2002). The main opponents of wildlife feeding are wildlife agencies citing that anthropogenic feeding results in many negative factors for the recipient species. These include factors such as the spread of disease, establishment of unwanted introduced species, changes in behaviour towards humans, malnutrition caused by inadequately diverse foods in the diet, development of health issues related to diet (e.g. "angel wing") and most commonly, dependencies forming on human provide supplementary food (Francis et al., 1967; Green & Higginbottom, 2000; Orams, 2002; Ishigame et al., 2006; Zsivanovits et al., 2006; Jones & Reynolds, 2008; Jones, 2011a).

There is ambiguity about the positive and negative factors of wildlife feeding and its impacts on the recipient species as very few studies have been conducted exploring these effects (Chapman & Jones, 2010). With wildlife feeding, implications from both humans and recipient species should be considered. From the human perspective it is informative to evaluate the demographics of people feeding wildlife, if the time of day, week or season plays a role in the human engagement of wildlife feeding, or if there are any differences in the quantity and types of food people are offering wildlife. From the recipient species' perspective, it is important to understand what their natural behaviours are when anthropogenic food is not available and how their behaviour changes in response to anthropogenic food being made available.

Therefore, the main objective of this study was to evaluate the prevalence of wildlife feeding at the Victoria Esplanade, Palmerston North, New Zealand and if the local Mallard, *Anas platyrhynchos*, population was dependant on the provision of food. This was achieved by documenting the frequency and magnitude of anthropogenic feeding of Mallards and, describing the nutritional components of food being offered to the Mallards, which to my knowledge is the first study to do so. As foraging observations were not possible at night, short-term GPS monitoring of Mallard movements through the park and surrounding area was conducted to give insight into whether the urban Mallards were nocturnal foragers, and if so, where.

Methods

Study site

Feeding of Mallards was studied over a four-month period from February to June 2018, at the Victoria Esplanade, Palmerston North, New Zealand (40°22'15.1"S 175°37'03.0"E). The Victoria Esplanade comprises 19 hectares of bush walks, playgrounds, and picnicking areas that are all within proximity of the Manawatu River (Fig 2.1).

Figure 2.1. Aerial view of Victoria Esplanade, Palmerston North, New Zealand. Land Information New Zealand © LINZ.

One of the main attractions of the Victoria Esplanade is the 800 m^2 duck pond where ducks are commonly fed by people. Wildlife feeding is so prevalent that the Palmerston North City Council recently (summer 2017–2018) installed a sign with information about why people should not feed the ducks bread and listed alternative foods people should offer the ducks instead (Fig 2.2).

Kaua e whāngai i a mātou ki te parāoa.

- Kāore e tika ana te taioranga o roto, ka mate puku mātou.
- Ka horapa te taupori rakiraki.
- Ka takakinotia te papa rēhia me te wai ki te parahanga parāoa. Ka riro te papa i te rīroi.
- Ka ngaro haere ngā pūkenga rapu kai e tika ana mā te punua rakiraki.

He pai kē te kānga, te wīti me te kano.

Kia ora rā!

Please don't feed us bread or quackers.

- It is nutritionally unbalanced and can make us sick.
- It leads to over population
- Uneaten bread pollutes your park and our water. It also attracts rodents.
- Our babies never learn to forage like real ducks should.

We prefer corn, grain and seeds.

Quanks.

Figure 2.2. Sign installed by the local council next to the duck pond. The sign contains reasons why bread should not be provided and has alternative foods that should be fed to ducks.

Observational hours

Observations were made between 1 h before sunrise and one hour after sunset as visibility was poor outside these hours. Days where rainfall exceeded 10 mm were excluded as Mallards would seek shelter under vegetation and therefore could not be included in the observations. Observations made during February and March were considered "summer months" (106.75 hours), whilst observations made between May and June were considered "winter months" (104.75 hours). Additionally, observations made between Monday till Friday was recorded as "weekdays" (140 hours), whereas Saturday and Sunday were noted as "weekends" (71.50 hours).

Anthropogenic food supply

When members of the approached to feed the Mallards, they were asked if I could weigh their food (on a digital scale to the nearest gram; Ohaus model cs 2000) to determine how much food was being offered to the Mallards. The following information was also collected while people were feeding the Mallards: food type being offered, the brand of food (where applicable), the broad demographic breakdown of feeders (numbers of adults and children), and duration spent feeding the Mallards.

Nutritional value of food

The price and nutritional value of foods were collected for commercially sliced bread. The cost of each load of bread was determined by the lowest, non-discounted price found at retailers within Palmerston North, New Zealand. All nutritional values were obtained from the manufacturers packaging as outlined by New Zealand Food regulation (2015).

Mallard behaviour

Every 15 minutes, a spatial scan sample was conducted to record the total number of Mallards present and their general behaviour (Martin & Bateson, 1993). Behaviour was broken down into four categories: natural foraging, anthropogenic foraging, resting and preening (adapted from Johnsgard 1965). A total of 254 hours of behavioural observations were made over the four-month data collection period.

GPS monitoring

To monitor the movements of Mallards, GPS logger units were attached to the central tail feathers of individuals weighing more than 1 kg. The GPS units used were commercially available iGot-U GT-120 logger (Mobile Action Technology Inc., New Taipei City, Taiwan).

Each GPS unit was removed from its casing and sealed in shrink-wrap tubing to waterproof the device. The final dimensions of the unit were 43 x 23 x 8 mm and they weighed ~16 g. The devices were set to record the GPS coordinates of the Mallard every 2 minutes. Mallards were tracked for two nights and one full day. Due to difficulties in capturing ducks and securely affixing the loggers, only two of a proposed 20 Mallards were successfully tracked. Co-ordinates were uploaded into QGIS 3.6.6 (2019) to observe the area covered.

Statistical analysis and ethics

All statistical analyses were conducted using the open-sourced statistical program R, version 3. 5. 1 by R Core Team (2018) with a significance level of $p<0.05$. Multiple t-tests were used to compare the effects of the season (summer versus winter) and day type (weekday versus weekend on various aspects of human behaviour (quantity feed, duration of feeding).

A weighted average of nutrition was obtained by averaging the expected nutrition of bread fed at each feeding event. Expected nutrition was calculated by using nutritional information per 100 g provided on packaging from manufactures and applying those values to weights of bread offered to Mallards.

The use of Mallards in this study was approved by the Massey University Animal Ethics Committee protocol number 19/92. The Massey University Human Ethics Committee deemed there would be miminal impact for individuals participating in this study. Permission was granted by the Palmerston North City Council to conduct this study on public land.

Results

Human and wildlife feeding interaction

A total of 133 observations (86 during summer and 49 during winter) of people engaging in wildlife feeding were recorded during the study period. On average, people engaged in wildlife feeding spent more time and provided more food during the summer months than the winter months (4.41 mins versus 3.31 mins and 502.8 g 418.5 g, respectively). Additionally, there was a higher number of wildlife feeding occurrences per hour across summer months than during winter month (0.62 versus 0.43 feeding events per hour, respectively). However, none of the differences observed per season was significant ($P>0.05$).

Of the 133 observations of people engaging in wildlife feeding, 61 occurred during weekdays and 74 occurred during the weekend, which resulted in a significant difference of wildlife feeding occurrences per hour during the weekends than during the weekdays ($P=0.008$). During weekdays on average, people would engage in wildlife feeding for significantly longer durations (5.17 mins vs 3.28 mins, $P=0.007$), but there were no significant differences in the quantity of food offered (509.7 g vs 442.1 g) than during the weekend.

Table 2.1. Demographic group sizes engaged in wildlife feeding at the Victoria esplanade

Number of children in the group		Number of adults in the group					
		0	1	2	3	4	5
	0	-	5	16	1	1	-
	1	-	26	23	4	-	-
	2	1	11	25	-	1	1
	3	-	3	7	1	1	-
	4	-	2	3	-	-	-
	5	-	-	-	-	-	-
	6	-	-	-	1	-	-

There was no significant variation in average group size between season or weekdays vs weekends, with an average mean group consisting of one child and two adults. Most groups (63.9%) consisted of one to two children and one to two adults were the most frequent groups visiting the pond to feed the Mallards (Table 2.1). People engaged in wildlife feeding between 8 am and 8 pm, with people most frequently engaging in the activity between 3 and 4 pm (1.14 visits per hour, Fig 2.3). The average number of visitors that feed the Mallards per hour between 8 am and 8 pm was 0.56 visits per hour. The amount of food being offered per visit each hour correlated with a total number of visits per hour (Fig 2.3), except for feeding between 6 pm and 7 pm which was much higher than the mean.

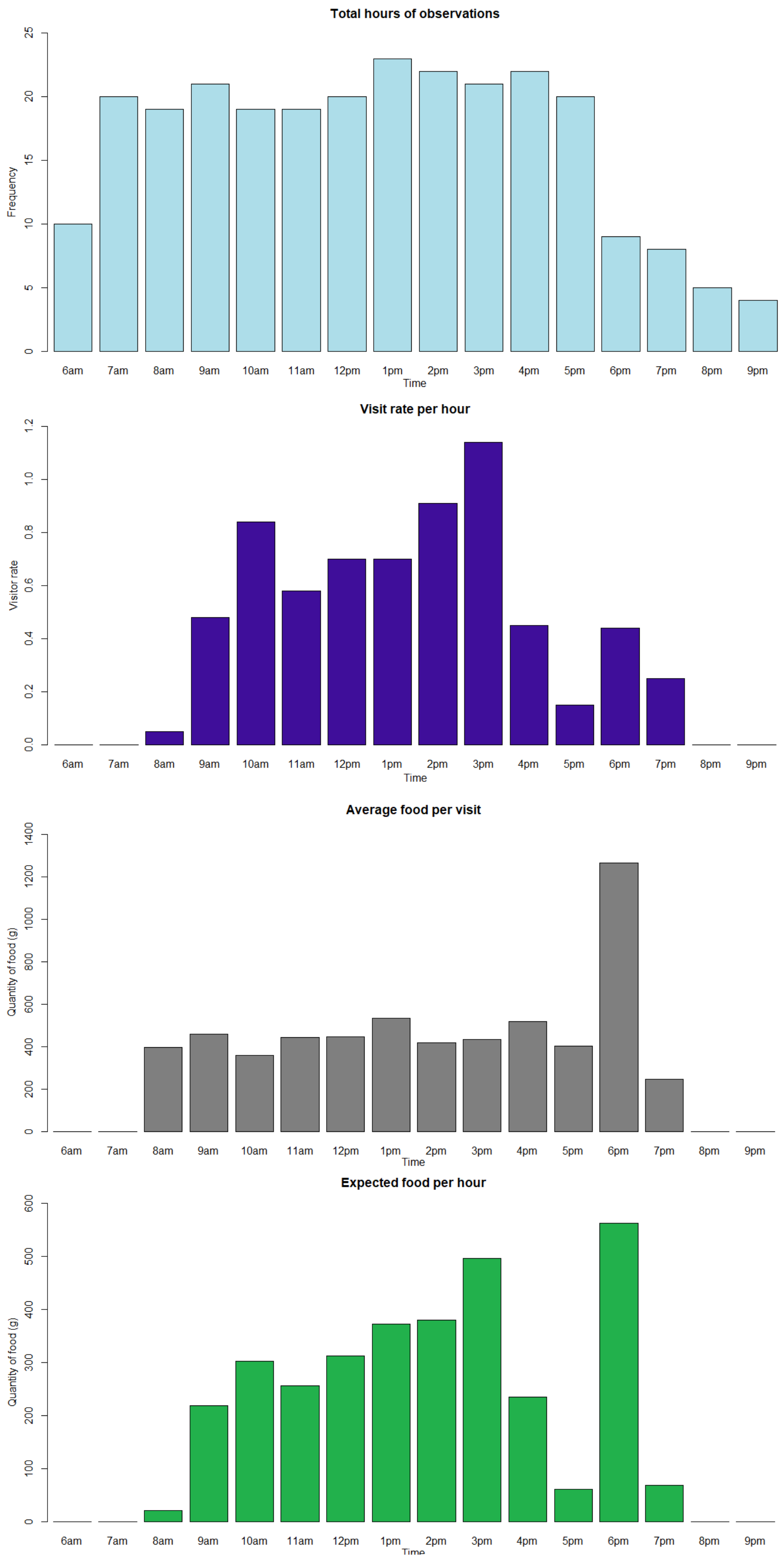

Figure 2.3. A-Total observational hours conducted throughout the day. B- Visitor rate per hour adjusted for total hours observed. C- Average food per hour, not adjusted for total hours observed. D- Expected food per visit, the result of visitor rate per and average food per hour.

Across all feeding events, a total of 62,111 g of assorted anthropogenic food (Table 2.2) was offered to the Mallards. While a diverse range of food offered was recorded, bread (multi-grain, white, wholegrain and wholemeal) comprised the vast majority (52,031 g or 83.8%) of the food being offered, with commercially sliced bread making up 88.8% (46,208 g) of total bread offered to the Mallards.

Table 2.2 Total observed food offered to Mallards at the Victoria esplanade by grouping and food type.

Category	Food type	Total (g)
Bread (Sliced)	Multigrain	1468
	White	46702
	Wholegrain	520
	Wholemeal	3341
Bakery goods	Buns	3295
	Fruit cake	486
	Fruit loaf	82
	Hot cross buns	1105
	Naan	171
Junk food	Fried Chips	139
	Crackers	132
	Rice bubbles	302
	Rice crackers	24
“Healthy foods”	Corn	1770
	Popcorn	-
	Rolled oats	1193
	Seeds	1381
Grand Total		62111

Nutrition of food being offered

There was a clear preference for people to offer cheaper bread to the birds (Table 2.3). Two-thirds of the commercially sliced bread recorded came from brands that cost $2.00 or less per loaf (Gold Max, Homebrand, Rivermill and Value; 31,180 g of the total of 46,208 g, 67.5%). Bread tended to contribute similar percentages of macronutrients to their respective total feed contributions, however, Homebrand, which constituted 22.8% of the sliced bread, provided a high percentage of saturated fats (53 g, 28.8%) and only 26 g (18.5%) of dietary fibre. Although there was variation in nutritional values between brands of bread, there was little variation between the average nutritional values of bread and the weighted average of all bread on offer (Fig. 2.4).

Table 2.3. The total macronutrient contributions of commercial sliced bread brands from all feeding observations at the Victoria Esplanade. Percentage of total contribution for each brand in parentheses. Bread brands are listed in ascending price.

Bread Brand	Price per loaf (NZD)	Quantity (g)	Energy (Kj)	Protein (g)	Total Fat (g)	Saturated Fat (g)	Carbohydrate (g)	Sugar (g)	Dietary Fibre (g)	Sodium (mg)
Value	$0.99	7,148 (15.5)	70,635 (15.0)	628 (15.7)	137 (15.0)	29 (15.9)	3,118 (14.7)	242 (17.8)	244 (17.1)	28,429 (15.1)
Homebrand	$1.00	10,542 (22.8)	109,637 (23.3)	938 (23.4)	232 (25.3)	53 (28.8)	4,891 (23.1)	316 (23.2)	264 (18.5)	43,222 (23.0)
Rivermill	$1.75	5,224 (11.3)	52,032 (11.0)	466 (11.7)	101 (11.0)	21 (11.4)	2,272 (10.7)	181 (13.3)	178 (12.5)	20,218 (10.8)
Gold Max	$2.00	8,236 (17.8)	82,360 (17.5)	652 (16.3)	118 (12.9)	25 (13.5)	3,849 (18.2)	199 (14.6)	206 (14.5)	34,591 (18.4)
Nature's Fresh	$2.95	6,103 (13.2)	64,582 (13.7)	555 (13.9)	135 (14.7)	12 (6.8)	2,943 (13.9)	183 (13.4)	214 (15.0)	23,733 (12.6)
Tip Top	$2.99	4,294 (9.3)	44,953 (9.5)	352 (8.8)	90 (9.9)	17 (9.4)	2,054 (9.7)	102 (7.5)	108 (7.6)	18,763 (10.0)
Molenberg	$3.19	1,479 (3.2)	14,176 (3.0)	141 (3.5)	38 (4.1)	15 (8.1)	568 (2.7)	39 (2.9)	91 (6.4)	5,642 (3.0)
Ploughmans	$3.29	2,068 (4.5)	21,798 (4.6)	174 (4.3)	48 (5.3)	8 (4.3)	956 (4.5)	65 (4.7)	82 (5.7)	8,272 (4.4)
Quality Bakers	$3.29	636 (1.4)	6,691 (1.4)	52 (1.3)	12 (1.3)	3 (1.4)	311 (1.5)	19 (1.4)	20 (1.4)	2,881 (1.5)
Vogels	$3.99	478 (1.0)	4,350 (0.9)	43 (1.1)	5 (0.5)	1 (0.8)	193 (0.9)	15 (1.1)	20 (1.4)	2,032 (1.1)
Grand Total		46,208	471,213	4,001	916	183	21,156	1,362	1,425	187,783

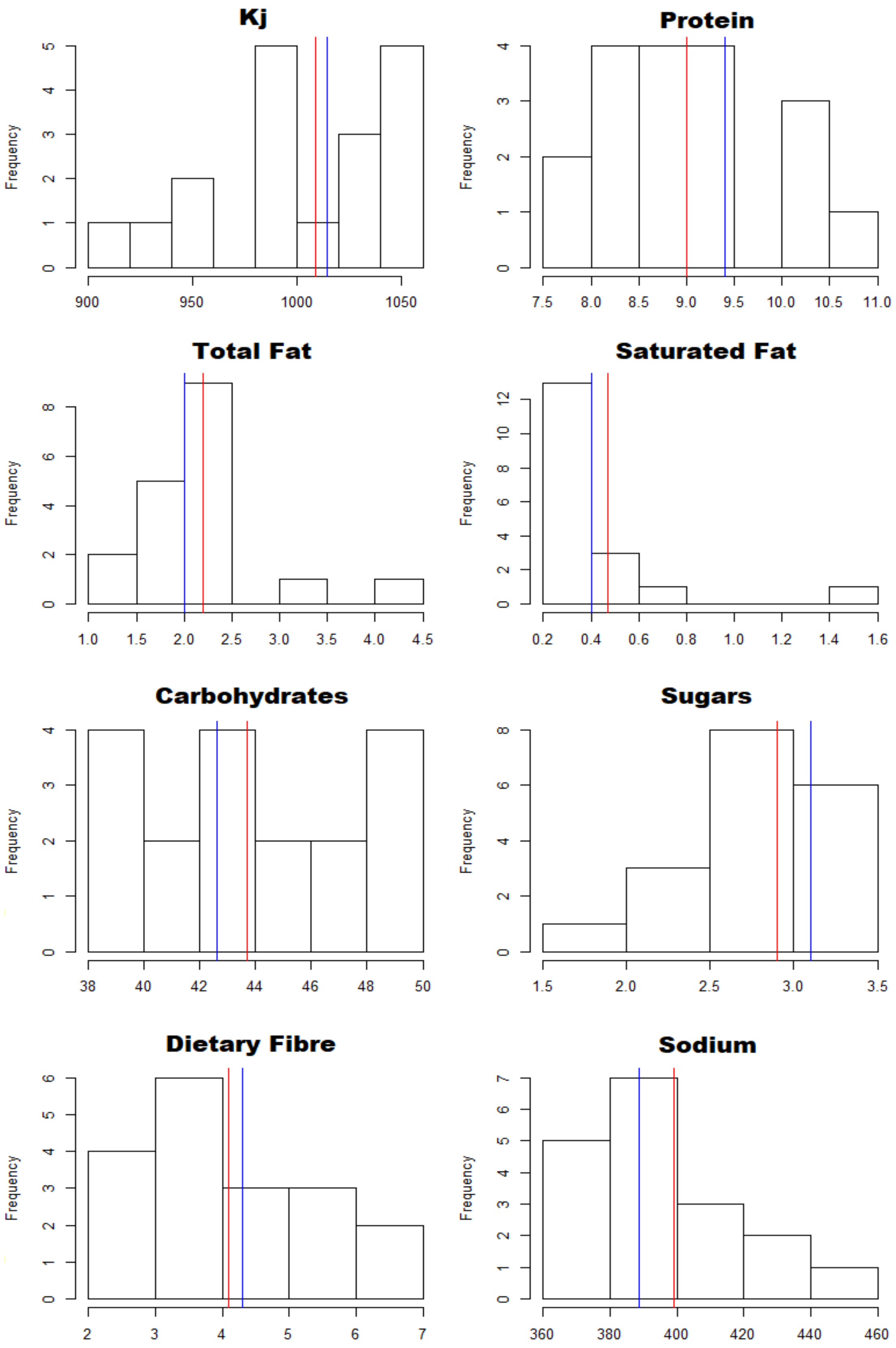

Figure 2.4. Diversity of bread nutrition values per 100 g. Red line—average value of all bread brands offered. Blue line—weighted mean of all bread given to Mallards

Mallard activity

The total number of the Mallards found in the pond and surrounding grassland of the Victoria Esplanade varied throughout the day (Fig. 2.5). In the mornings, relatively few individuals were present, but the number rose as birds arrived at the site (typically by flying in). Numbers plateaued from late morning to mid-afternoon, after which ducks would gradually leave the location. This pattern was similar in summer and winter, though numbers were lower in winter and the shorter days in winter meant that ducks spent less time overall near the pond.

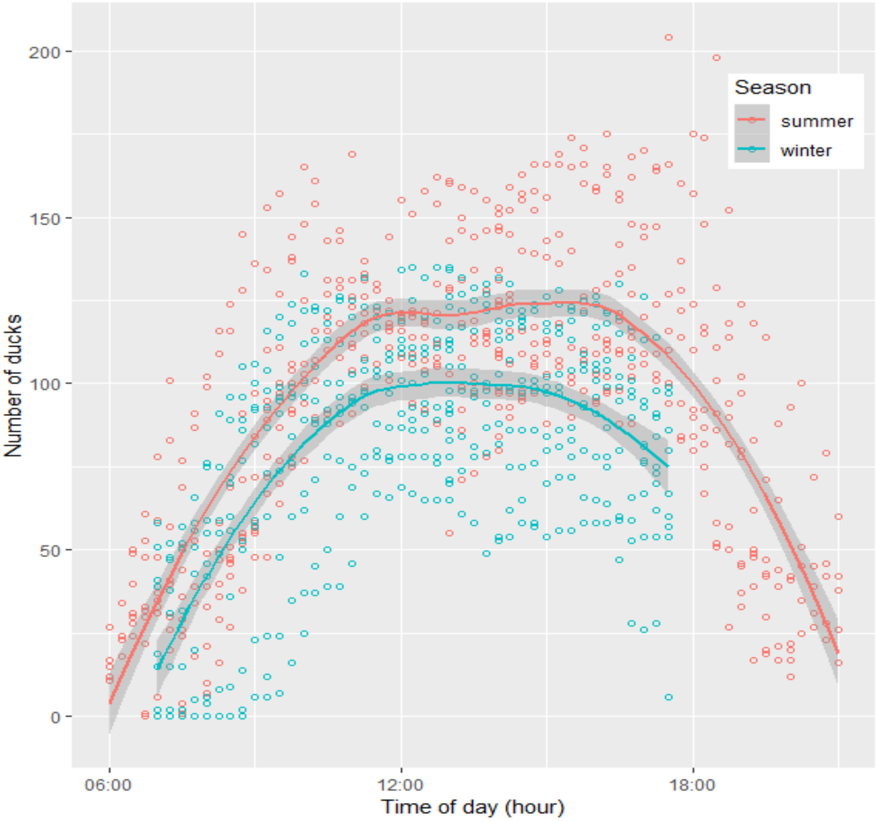

Figure 2.5. The population of Mallards at the Victoria Esplanade throughout the day. Lines are lowess spline showing average population size at that given time. The time range in winter was shorter due to shorter daylength within which observations could be made.

In the absence of anthropogenic food, the present Mallard population maintained a low level of natural foraging on grass at any given time (9.7% of the population foraging) (Fig. 2.6). When anthropogenic food was offered, the vast majority of ducks (78.3% of the mean present population) would forage upon the food being offered. A very small proportion (2.2%) still foraged on natural food sources even in the presence of anthropogenic food. Season or day type had little effect on the total number of ducks present during wildlife feeding events (summer 81, winter 82, weekday 83, weekend 81) such that on any given feeding event an average of 82 Mallards would forage on foods being offered to them from humans.

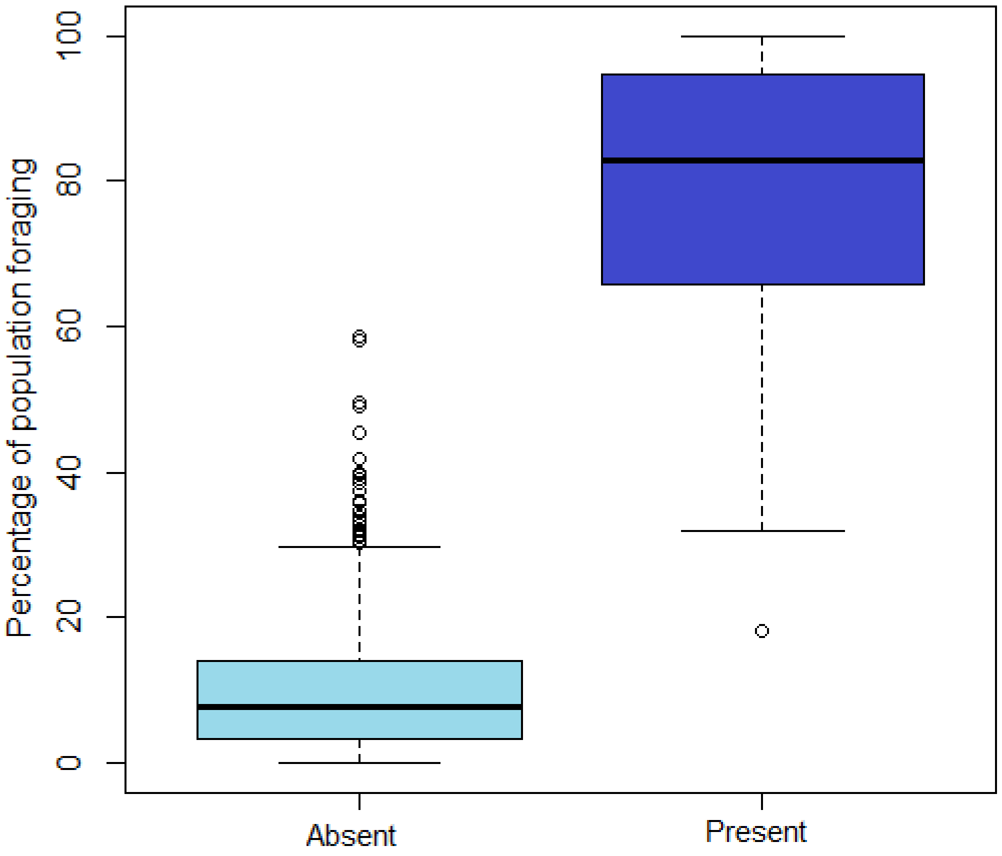

Figure 2.6. Percentage of Mallard population at the Victoria Esplanade foraging during the absence and presence of wildlife feeding.

GPS Results

From the two successfully GPS tracked Mallards, birds did not just stay at the pond but foraged around the surrounding areas (Fig. 2.7). One bird stayed within the boundary of the Victoria Esplanade whilst foraging, but the other individual was recorded in the bush on the boundary between the Victoria Esplanade and the Manawatu River. Furthermore, this Mallard was recorded spending time in the Manawatu river up to 1 km away from the pond. Incidental observations at another body of water 1 km away (Hokowhitu lagoon, another commonly used area for wildlife feeding) confirmed the movement of GPS-tagged birds outside of the Victoria Esplanade.

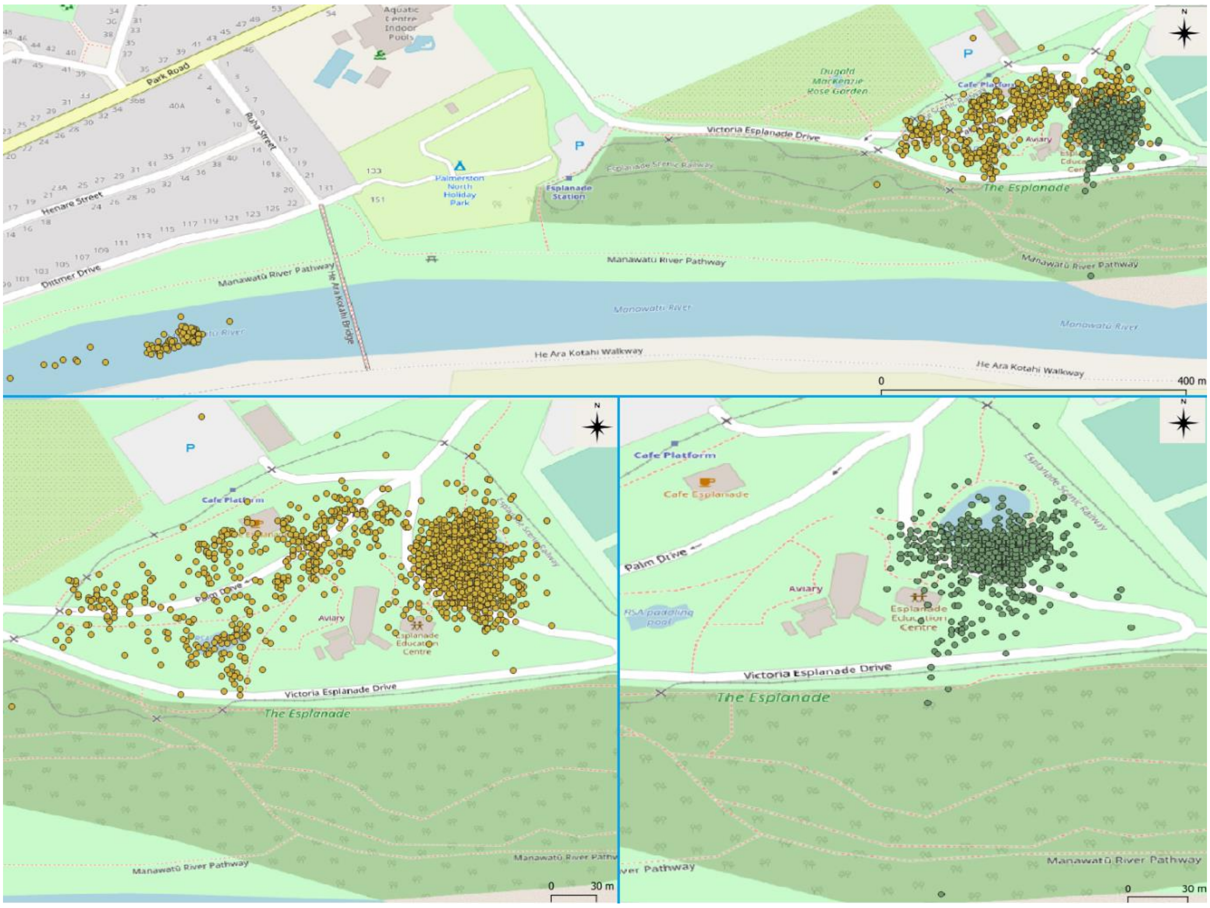

Figure 2.7. Upper map—The home range of the two GPS-tagged Mallards within the Victoria Esplanade and surrounding area. Bottom left and bottom right—the area covered by each Mallard within the Victoria Esplanade.

Discussion

The focus of this study was to determine the extent that people engage in feeding Mallards at the Victoria Esplanade in Palmerston North, New Zealand. A secondary aim was to investigate the nutritional value of the foods being offered and the influence of human feeding on Mallard foraging behaviours. A month before the start of behavioural observations, the local council had installed new signage stating people should not feed the wildlife bread but suggested other alternatives such as corn, grains and seeds. It is not known what effect this sign had on the frequency of people engaging in wildlife feeding, but the sign did not deter people entirely from feeding wildlife. Although people offered the Mallards a range of different food types, including some of the foods suggested by the local council, I found that 83.8% of the food offered to the ducks was bread, which is comparable to a previous report of 88.1% of New Zealand households offering bread to wildlife in their backyards (Galbraith et al., 2014).

In addition to people mostly feeding wildlife bread, in New Zealand, there is an increase in the proportion of people engaging in wildlife feeding during the winter months (Galbraith et al., 2014). From my findings, wildlife feeding of Mallards was observed during both the summer and winter months. However, there was a greater number, although not significant, of observations of wildlife feeding during summer months than during winter month (0.62 versus 0.43 visits per hour). Furthermore, people did offer more food during the summer months than winter per visit (502.8 g versus 418.5 g). Another interesting, but not entirely surprising result, was that during the weekends there was a greater rate of wildlife feeding than during the rest of the week (0.83 versus 0.36 visits per hour). People spent longer feeding the ducks in summer than in winter, probably because they tended to bring more food, which would take a longer time to distribute.

There has been a shift from wildlife feeding being a response to animal welfare in winter to a recreational activity for urban-dwelling humans (Jones, 2011b). The findings in this study support this, with greater feeding levels during summer rather than winter as well as during weekends than weekdays. People tend to have more free time to partake in this activity during weekends as the standard working and education week in New Zealand is Monday through Friday. Further support for wildlife feeding being a recreational activity is indicated by the times of the day that people engaged in the activity. With the average group size of two adults and one child or 82% of observed groups being made up of at least one adult and child, wildlife feeding is most likely an activity families are doing together.

From this study, I cannot prove why people would offer more food to Mallards during summer months, but in any case, season affected the number of people feeding the Mallards at the Victoria Esplanade. A possible explanation for the high participation of wildlife feeding in summer is humans have more free time and the warmer conditions promote a desire to be outdoors. The total number of Mallards present at the pond varied with the season with more individuals present during summer than during winter months. One possibility is that the difference in numbers relates to the amount of anthropogenic food available seasonally, with more feeding visits and more food being offered in summer. Under the ideal free distribution (see Fretwell (1969) for details) I would expect the numbers of ducks to vary similarly, as individuals will distribute themselves between sites in response to food availability to maximise their foraging effort/return ratio (Newton, 1998). In winter, individuals may have opted to forage elsewhere due to the decrease in anthropogenic food, and foraging may itself be improved in the wetter winter conditions. Alternatively, the high number of Mallards present in summer could be the result of the presence of young fledgeling Mallards, as the breeding season of Mallards in New Zealand occurs between August and December (Williams & Roderick, 1973). Furthermore, this time period is accompanied by a moult that will limit the flight capacities of adult Mallards (Sheppard, 2017).

Across all time periods and seasons, there was a base level of natural foraging. However, when people approached the pond and surrounding area to feed the ducks, there was a rapid change of foraging behaviour as they came forward to receive the food being offered. During periods when anthropogenic food was not available, approximately 9.7% of the population would be foraging for naturally occurring foods. Interestingly, even in the presence of anthropogenic food, 2.2% of the population were still foraging on natural foods (e.g., acorns and grass), possibly due to high competition to obtain anthropogenic foods (Fretwell, 1969). As Mallards are opportunistic omnivores (Kleyheeg et al., 2016), it was not surprising to see them changing focus on what foods they are foraging in the presence of anthropogenic feeding. It was surprising, however, that there was still a base level (albeit be of a very low level) of the population still foraging on naturally occurring foods, contradictory to my predictions. This finding suggests that not all Mallards present at the pond rely on humans to feed them to meet their nutritional needs.

A lack of complete reliance on anthropogenic foods to meet their energy needs is further supported by the two GPS-tracked Mallards in this study. These two birds showed that ducks in the Victoria Esplanade forage across the entire park and surrounding river for food. One bird fed under palm trees and oak trees where nuts and acorns are available and other birds were recorded moving to other bodies of water such the Hokowhitu Lagoon. Urban Mallards have been documented having a foraging range of 1–2 km away from their roosts (Legagneux et al., 2009), thus it was not surprising to see Mallards from the Victoria Esplanade foraging at the Hokowhitu Lagoon 1 km away. Therefore, it can be concluded that Mallards at the Victoria Esplanade supplement their diet with (semi) natural food and do not spend their entire day waiting for anthropogenic food provisions.

It would be problematic if Mallards relied only on anthropogenic foods to meet their total nutritional needs. There was a high proportion (67.5%) of cheaper bread brands ($2.00 or less per loaf) fed to the Mallards in this study. Although the nutritional value between brands of bread varied, the weighted mean of bread nutrition offered did not vary greatly from that of the mean nutritional value of bread. However, as bread is relativity high in carbohydrates and low in other dietary macronutrients (i.e., protein and dietary fibre) (Friedman, 1996; Dewettinck et al., 2008), there would likely be discrepancies in the nutritional intake of urban Mallards compared to those on an exclusively natural diet (Ottoni et al., 2009). Additionally, nutrient unbalanced diets are believed to be the cause of wing deformities such as angel wing (Flieg, 1970; Kear, 1973). Angel wing is caused by muscles of the carpus not being able to support the weight of developing flight feathers, causing the wing to rotate outwards at the carpus (Francis et al., 1967). It is believed that diets high in energy (carbohydrates) allowing for the rapid growth of flight feathers, with inadequate levels of protein in the diet to facilitate muscle development, is the probable cause of angel wing. However, excessive protein in the diet can also cause musculoskeletal valgus deformations (Zsivanovits et al., 2006). Nevertheless, diet is an important aspect of developmental growth and the addition of unnaturally occurring foods resulting in individual birds to grow faster than usual (Zsivanovits et al., 2006). During this study, no individuals were observed with wing deformities, but there have been historical observations of angel wing occurring in the local Mallard population.

In addition to bread being nutritionally imbalanced for Mallards, the amount of anthropogenic food being offered would not be sufficient to meet metabolic requirements for the entire observed population. With an average of 82 Mallards trying to forage on whatever is on offer at any given feeding event, assuming each Mallard got an equal share of the food on offer, each Mallard would receive 5.9 g of anthropogenic food per feeding event. If this 5.9 g was bread, each Mallard would only receive approximately 59.5 Kj per feeding event. McEwan and Koelink (1973) calculated a resting metabolic rate of male and female Mallards to be 508.36 and 409.57 Kj/day, respectively. Thus, a male or female Mallard would require, respectively, a minimum of 8.5 or 6.8 feeding events per day just to meet their resting metabolic needs. Since it can be expected that there would be just six occurrences of wildlife feeding per day at the Victoria Esplanade, on average birds would not be expected to cover even their basal energy needs.

From the results obtained in this case study, I can confidently say that this population of Mallards does not rely on anthropogenic food to meet 100% of their dietary needs. However, if anthropogenic food is available, individuals are more likely to forage on this resource than on naturally occurring foods. Due to the low level of anthropogenic food being made available, and thus high competition to obtain this limited resource, some individuals may choose not to forage on anthropogenic food when it is available. This is supported by anecdotal observations and GPS movements of Mallards foraging in the surrounding area of the Victoria Esplanade. Finally, I have evidence to support statements on wildlife feeding now being primarily a recreational activity for families. Although anthropogenic food does not make up the entire diet of this population of Mallards, their diet is not 100% natural and thus a semi-artificial diet should still have an impact on their gastrointestinal physiology and overall health.

Chapter 3

Differences in body composition between urban and rural Mallards, *Anas platyrhynchos*.

Chapter 3: Differences in body composition between urban and rural Mallards, *Anas platyrhynchos*.

Abstract

Mallards, Anas platyrhynchos, *are opportunistic omnivores that have a highly responsive gastrointestinal system such that their digestive organs are a representation of the availability of food in their habitat. As urban Mallards consume considerable amounts of low-fibre, high carbohydrate foods via anthropogenic feeding, I predict that urban Mallards would have smaller gastrointestinal tract organs and higher fat levels than rural ducks. I compared gross internal body composition of Mallards in a modified environment with high levels of feeding by humans and Mallards in rural habitats. I also evaluated other health indicators including fat deposit size, gut parasite levels, liver fat content and hemosiderin levels. Some significant differences were found between the rural and urban populations, but in the opposite direction to predictions. Urban birds had larger, rather than smaller, gizzards and caeca, and there was no difference in fat stores compared to rural birds. Rural birds had larger pectoralis major muscles. These differences are probably associated with broader ecological and behavioural factors (urban birds feeding on acorns and nuts resulting in larger gizzards; rural birds likely having greater flight activity) than with the provision of anthropogenic food per se. Longer caeca in urban birds could, however, relate to immunity rather than microbial fermentation of cellulose. Overall, while urban and rural environments evidently affect Mallard physiology, no obvious concerns for wildlife health were found in this study.*

Introduction

With an increasingly urban human population (Oro et al., 2013; McDonnell, 2015) more people are becoming limited in their engagement with wildlife (Jones, 2011a). One of the methods people in urban areas are engaging with nature is through their local parks by feeding animals natural and anthropogenic foods (Jones, 2011b; Cox & Gaston, 2018). In New Zealand, 46.6% of households engage in wildlife feeding, with bread constituting 88.1% of the food offered (Galbraith et al., 2014). Given that urban landscapes have been altered to human needs and as anthropogenic foods are absent in the wild, there is a difference in food availability between the urban and rural settings (Chace & Walsh, 2006; Amrhein, 2014). Changes in food availability and diet will likely affect the total quantity of fats, proteins and carbohydrates that urban wildlife will ingest (Kohl et al., 2017).

The digestive tracts of birds are known to be highly phenotypically flexible and responsive to the composition and nutritional value of the foods being digested (Battley & Piersma, 2005; Champagnon et al., 2011). It has been suggested that having a gastrointestinal (GI) tract that responds to food availability ensures optimal digestion of nutrients and reduces metabolic costs associated with an inefficient GI system (Battley & Piersma, 2005; McWhorter et al., 2009). Organs that have been found to change in response to food quantity and intake are the gizzard, small intestine and liver (Battley & Piersma, 2005).

Mallards, *Anas platyrhynchos*, are opportunistic omnivores that have a highly responsive GI system. Miller (1975) found that the Mallards' GI tract rapidly changes in response to highly indigestible foods being introduced to the diet. A diet high in indigestible fibre has been shown to result in a significant elongation of the caeca, small intestine and large intestine (Miller, 1976). The gizzard is a large and heavy organ in birds responsible for the mechanical breakdown of food, and its size can reflect the quantity and quality of foods being consumed (Moore, 1998b). There may also be pressures to minimise mass to help facilitate flight (Moore, 1998a).

Given that the diet of a Mallard varies between habitats as food availability and abundance differs, i.e. fish, insects, molluscs, plant material, seeds (see Jorde et al., 1983; Khan et al., 1996; Guillemain et al., 2000; Arzel & Elmberg, 2004; Chapman & Jones, 2011), and their GI tract responds to the types of foods being ingested, it is likely that consumption of anthropogenic foods in urban areas results in changes in the GI tract. Specifically, if birds are eating lower fibre foods, I predict there will be shorter GI tracts and smaller gizzards in urban birds. Additionally, the greater intake of carbohydrates from anthropogenic food and lack of foraging effort required to obtain it raises the possibility that there are direct health impacts (i.e. increased fat levels) for Mallards with an urban lifestyle.

In this study, I compared the body composition of rural and urban Mallards in New Zealand. I compare the masses of dissected muscle and digestive organs, and fat deposits, between rural and urban birds. I also test for differences in other health indicators (parasite loads, liver fat and metal deposits). By looking at multiple indicators it provides a good chance of detecting feeding-related impacts on the health of urban ducks at a site regularly provisioned with anthropogenic foods.

Methods

Animal collection

Adult Mallards were collected over 10 weeks between February and May 2018. Urban ducks were collected from the Victoria Esplanade (40°22'15.1"S 175°37'03.0"E) and the Hokowhitu Lagoon (40°22'09.8"S 175°37'45.1"E) (Fig. 1) in Palmerston North, New Zealand, captured by hand or by walk-in cage trap.

Rural Mallards were initially collected using baited walk-in cage traps across multiple sites across the Manawatu region (40°18'15.9"S 175°30'22.6"E, 40°18'29.9"S 175°41'01.3"E, 40°18'06.9"S 175°45'53.6"E). Additional rural Mallards were donated by Fish and Game Wellington from reclaimed illegally shot game near one of the sites cage trapping was used (40°18'15.9"S 175°30'22.6"E).

Ducks were either euthanised at the site of capture or at Wildbase hospital, Massey University, Palmerston North, New Zealand. Euthanasia was by sedation by an intramuscular injection of 1.0 mg/kg of midazolam (Midazolam Injection, Pfizer, Auckland, New Zealand) and 4.0 mg/kg of butorphanol (Butorgesic, Ilium, Auckland, New Zealand) followed by an intravenous injection of pentobarbital Pentobarb 300, Provet, Auckland, New Zealand) into the medial metatarsal vein (as shown in Bexton and Couper 2014)

Figure 3.1. Aerial map of capture sites of rural and urban Mallards in the Manawatu. Top left: all capture sites. Bottom left: close up of urban capture sites. Right: Location of the study region in the North Island of New Zealand. QGIS 3.6.3. Google Maps, © Google.

Carcasses were stored frozen at -20˚C until dissection. Ducks were sexed by plumage, gonads and the presence (male ducks) or absence (female ducks) of the syringeal bulla, a pear-shaped uniformly-ossified structure found on the left side of the trachea (Warner, 1971). In total, I analysed 12 rural females and 8 rural males, and 11 urban females and 10 urban males.

Morphometric assessments

All measurements were conducted using Vernier callipers to ±0.1 mm unless otherwise specified. Before dissection, bill length, total head length and tarsus were measured as outlined by Moore and Battley (2006). Wing length was recorded using the maximum chord method (Spencer, 1976) by flattening the wing along a steel ruler (±1 mm). Finally, body mass was recorded on a digital scale (±1 g). During dissection, the right-hand side of the keel and the right coracoid were exposed. Morphometric measurement of the width of the keel and coracoid were taken following Piersma et al. (1984) as shown in Fig. 3.2.

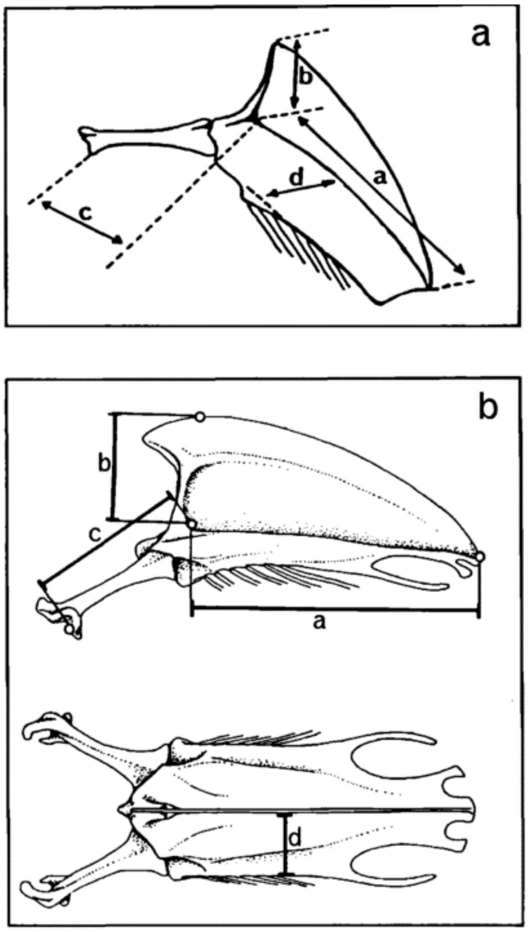

Figure 3. 2 Measurements of the sternum and coracoid. From Piersma et al. (1984).

The right-hand side pectoralis major and supracoracoideus muscles were removed and collected, then the entire keel removed to expose the cardiovascular organs and GI tract. The right leg was also removed, and muscles dissected out.

Before removal, the heart width (greatest width from the right atrium to the left atrium), length (greatest length from the right atrium to apex) and coronary band thickness (greatest width of fat) were measured (±0.1 mm). Each heart chamber was opened and rinsed with water to remove any congealed blood before drying. The liver was measured *in situ* along the body axis (length ±0.1 mm) and carefully removed. The abdominal viscera were then removed and laid straight, but not stretched, on a wet surface. The spleen and mesenteries were removed leaving only the GI to be separated into the proventriculus, gizzard, small intestine (gizzard to the anterior junction of the caeca), large intestine (anterior junction of the caeca to the rectum) and caeca (as outlined by Moore & Battley, 2006). The proventriculus length, large intestine length, and gizzard external length, width and depth were all measured.

The gizzard was cut in two along the medial plane, allowing for gizzard muscle and koilin thickness (membrane formed by sections of glands of the gizzard) to be measured at the thickest. Lengths of the small intestine and each caecum were measured using a steel ruler (±1 mm). After external measurements of all organs were taken, the organs were opened, and their contents removed. Contents of the small intestine, large intestine, and caeca were collected and sifted through a 355 μm mesh filter to extract gut parasites. The gut parasites were then stored in 70% ethanol for retrospective classification.

All muscle, fat and organ samples were placed into pre-weighed, labelled aluminium dishes and the fresh weight recorded (±0.001 g). After the fresh weight of the liver was taken, a 1-cm cube of the liver was removed for histology and weighed. All samples were then dried at 70°C for seven days before being cooled in a desiccator and reweighed to obtain the dry mass. The entire dried liver was placed into an envelope made of filter paper and individually submerged in a sealed glass bottle of 100 ml petroleum ether (Fisher chemical, Loughborough, United Kingdom). The petroleum ether from each bottle was removed and replenished every four days until the mass of the liver did not change for two consecutive days. Fat mass of the liver was obtained by subtracting the fat-free dry mass from the dry mass, and the resulting fat mass was expressed as a percent of the dry mass. The dry mass of the liver was corrected to include the sample removed for histology before statistical analysis.

Liver histology

Formalin-fixed samples of liver were prepared using standard histological techniques and tissue staining as described in Cork (2000) to assess the degree of hemosiderin (iron-storage complex) and by Wight & Siller (1975) to assess lipid deposition in hepatocytes. A minimum of twenty high powered fields (hpf) of hepatocytes was evaluated for each bird. A subjective score of 0–3 was assigned based on the presence of hemosiderin and lipid deposition by an avian veterinary pathologist.

Haemosiderin deposition in the liver were assigned scores dependant on the quantity of pigmentation of the cytoplasm of hepatocytes and Kupffer cells: 0 – no pigment present or only very occasional granules in the cytoplasm of hepatocytes: 1 – pigment present in the cytoplasm of some hepatocytes and occasional Kupffer cells: 2 – pigment present in the cytoplasm of most hepatocytes and regularly in Kupffer cells: and 3 – heavy load of pigment present in the cytoplasm of all hepatocytes and swelling the cytoplasm of Kupffer cells.

Lipid deposition in the liver was also assessed following a similar scoring system based on the presence of fat vacuoles in hepatocytes and severity of distortion of the hepatocytes: 0 – no fat vacuoles present in hepatocytes: 1 – occasional fat vacuoles in the cytoplasm of hepatocytes with no distortion of the hepatocyte size: 2 – fat vacuoles common in hepatocytes with some associated swelling of the hepatocytes: and 3 – fat vacuoles present in the cytoplasm of all hepatocytes with associated swelling and distortion of the hepatocytes.

One urban female's liver was too severely autolysed to interpret with any confidence and therefore was excluded was from the analysis.

Statistical analyses

All statistical analyses were conducted using program R (version 3.5.1) and to a significance level of $p<0.05$. Fat, organ and muscle dry weights were tested for normality using a Shapiro-Wilk test. Measurements and weights that did not follow a normal distribution were transformed using the Tukey transformation procedure in the 'rcompanion' package; this successfully normalised all non-normal variables except visceral fat mass.

We used external (lengths of the bill, total head and tarsus) and internal (all four sternum measurements) bone measurements in principal component analyses (PCA) to produce overall measures of body size. Wing length was not included in the external PCA as some individuals were undergoing wing moult. We used component 1 of the PCA used as a size measure and compared how well these PCA-derived size measures correlated with organ masses. While the external PCA explained 63% of the size variation between individuals, it was much less correlated with organ sizes than the internal PCA (which explained 52% of the variation in measurements). Therefore, we used PC1 of the internal size PCA as the size measure in analyses. Individual factor loadings were keel length 0.546, keel to coracoid length 0.590, keel width -0.216, keel depth 0.408 and coracoid length 0.374.

We tested for effects of habitat and sex on body composition via linear models ('lm' function) with habitat (rural and urban) and sex (male and female) as factors and body size (PC1 based on internal skeletal measurements) as a continuous additional covariate to account for differences in organ mass that may scale with size. Starting with a global model including interactions, the 'step' function in R was used to progressively simplify the candidate model via comparison of AIC values until the 'best' (lowest AIC) model was found. We compared all models within 2AIC units of the selected models where model simplification was supported. In most cases (17 of 26) there was no change in the identification of significant variables but in eight cases the less well-supported models failed to detect a main significant effect present in the main model. Of the 33 models tested, 11 were not significant or the models simplified to a null model with no variables. All factors in the significant final models are listed in Table 1. Scores from the liver histology hemosiderin and lipid deposition were compared using chi-square tests.

Scoring of liver histology hemosiderin and lipid deposition, in addition to total parasite counts, were compared using a chi-square test.

The use of Mallards in this study was approved by the Massey University Animal Ethics Committee (17/92). Permission was granted by the New Zealand Fish & Game Council to collect Mallards for this study. Additionally, the Palmerston North City Council approved the conduct of this study on the public-owned property of the Victoria Esplanade, Palmerston North, New Zealand.

Results

Muscle and cardiovascular

On average, males were heavier than females (means of 1,098.8±SD36.6 g for rural females, 1,121.0±116.8 g for urban females, 1,233.2±135.5 g for rural males and 1,185.0±94.7 g for urban males) but this difference largely reflected the larger body sizes of males (the only significant factor affecting mass was size; Table 3.1). Controlling for size, there were no differences in body mass between sexes or sites. The pectoralis major muscle varied not just with size (P=0.007), but also with habitat (P=0.021), with significantly heavier muscles in rural than urban ducks. Neither supracoracoideus nor leg muscles differed significantly between sites or sexes (Fig. 3.3, though supracoracoideus almost did with sex), but leg muscle mass increased with body size (P=0.017). The dimensions (length and width) of the heart differed between the sexes (larger in males; Table 3.1, Fig. 3.3) but there was no significant variation in the coronary fat band width.

Table 3.1. Summary of body composition data, and results of statistical tests for variation in body composition from habitat (rural versus urban), sex (female versus male) and body size (PC1). All means are given ± standard deviation. The effect of habitat, sex, size or any combination of the three were analysed via a linear step-down model (see methods). Statistical significance was defined as P<0.05 (bolded), while P<0.1 was considered a trend (values are shown but not in bold). Factors that were retained in the final model but had P>0.1 are recorded with an asterisk (*), whilst blank cells mean the factor was not retained in the final model. Model outputs are only shown for significant models.

										Female		Male	
		F_{df}	P	R^2	Habitat	Sex	Size	Interactions		Rural	Urban	Rural	Urban
Total body	Mass	$18.65_{1,39}$	<0.001	0.31			**≤0.001**			1098.8±96.6	1121.0±116.8	1233.2±135.5	1185.4±94.7
Muscle masses	Pectoralis major (g)	$6.85_{2,38}$	0.003	0.23	**0.021**		**0.007**			27.592±2.382	25.450±2.465	29.515±4.988	26.699±4.086
	Supracoracoideus (g)	$4.00_{1,39}$	0.052	0.07		0.052				3.633±0.384	3.827±0.726	3.999±0.375	3.628±0.565
	Leg (g)	$6.32_{1,39}$	0.016	0.12			**0.017**			9.746±1.383	10.247±1.835	11.291±2.108	10.697±1.791
Heart	Mass (g)	$2.41_{3,37}$	0.082	0.10						9.129±0.702	8.721±0.913	10.120±1.988	9.934±1.172
	Length (mm)	$4.30_{2,38}$	0.021	0.14	*	**0.018**				39.7±3.8	42.1±3.8	42.9±2.3	43.6±1.7
	Width (mm)	$4.27_{3,37}$	0.011	0.20	*	**0.002**	*	Habitat*Sex	*	28.4±4.4	30.0±3.4	32.9±1.8	31.7±1.9
	Band thickness (mm)	$1.53_{3,37}$	0.222	0.04						6.0±1.3	7.2±2.2	6.7±1.5	5.8±1.0
Liver	Mass (g)	$1.90_{7,33}$	0.102	0.14						9.769±3.689	9.564±1.980	11.592±3.039	10.855±2.303
	Length (mm)	$4.26_{3,37}$	0.011	0.20		*	**0.005**	Sex*Size	**0.035**	79.9±11.0	79.0±6.3	81.8±5.4	83.4±3.9
Pancreas	Mass (g)	$1.78_{7,33}$	0.125	0.12						0.882±0.260	0.859±0.297	1.100±0.251	1.097±0.359
Spleen	Mass (g)	$2.24_{7d,33}$	0.056	0.18	*	0.099	*	Habitat*Sex Habitat*Size Sex*Size Habitat*Sex*Size	* **0.017** * **0.043**	0.116±0.040	0.151±0.072	0.190±0.087	0.131±0.055
Proventriculus	Mass (g)	$1.65_{7,33}$	0.157	0.10						0.897±0.250	1.133±0.372	1.124±0.382	0.886±0.181
	Length (mm)	$6.01_{5,35}$	<0.001	0.39	*	*	**0.001**	Habitat*Sex Sex*Size	* *	35.8±3.3	36.7±3.5	41.6±4.9	37.5±3.7
Gizzard	Mass (g)	$8.52_{2,38}$	<0.001	0.27	**0.001**		**0.036**			9.550±1.453	11.146±2.075	9.981±0.989	12.978±2.950
	Length (mm)	$7.77_{2,38}$	0.002	0.25	**0.002**		**0.036**			39.0±3.2	42.5±4.2	41.1±3.4	45.1±3.5
	Width (mm)	$7.92_{3,37}$	<0.001	0.34	**≤0.001**	**0.006**				51.1±3.0	56.0±4.8	54.8±2.8	59.0±4.7
	Depth (mm)	$6.34_{2,38}$	0.004	0.21	**0.003**	0.079				30.6±2.6	32.4±2.8	31.4±1.6	34.7±3.2
	Muscle thickness (mm)	$19.77_{2,38}$	<0.001	0.48	**≤0.001**	**0.026**				18.6±3.3	23.5±3.4	16.3±2.1	21.8±2.9
	Koilin thickness (mm)	na	na	na						2.7±0.5	2.6±0.4	2.4±0.5	2.6±0.4

										Female		Male	
		F_{df}	P	R^2	Habitat	Sex	Size	Interactions		Rural	Urban	Rural	Urban
Small intestine	Mass (g)	$7.00_{1,39}$	0.012	0.13			**0.012**			5.721±1.253	5.365±1.206	6.6334±1.323	5.860±0.781
	Length (mm)	$9.6_{2,38}$	<0.001	0.30	0.082		**≤0.001**			1399.6±88.3	1474.7±127.1	1512.4±136.8	1555.6±54.8
Large intestine	Mass (g)	$3.13_{7,33}$	0.011	0.27	*	*	**0.004**	Habitat*Sex	*	0.538±0.184	0.670±0.259	0.514±0.101	0.615±0.208
								Habitat*Size	*				
								Sex*Size	*				
								Habitat*Sex*Size	0.080				
	Length (mm)	$1.51_{7,33}$	0.200	0.08						86.1±5.6	91.0±12.1	88.7±7.8	95.3±18.3
Caeca	Mass (g)	$3.61_{7,33}$	0.005	0.31	*	*	**0.001**	Habitat*Sex	*	0.561±0.124	0.610±0.067	0.616±0.128	0.727±0.208
								Habitat*Size	0.057				
								Sex*Size	0.089				
								Habitat*Sex*Size	0.074				
	Shorter length (mm)	$8.21_{2,38}$	0.001	0.27	**0.010**	**0.004**				126.5±20.9	143.2±14.2	145.0±20.5	157.4±7.0
	Longer length (mm)	$12.96_{2,38}$	<0.001	0.37	**≤0.001**		**0.009**			136.0±22.9	162.3±14.2	152.3±15.4	172.4±13.4
Fat masses	Furcular (g)	na	na	na						2.124±1.177	2.361±1.982	2.027±1.818	1.410±0.792
	Abdominal (g)	$3.72_{1,39}$	0.06	0.06	0.061					4.590±3.132	3.027±2.564	6.186±5.075	2.002±1.314
	Visceral (g)	$1.74_{3,37}$	0.18	0.05						1.700±1.370	1.895±2.083	2.796±2.872	0.383±0.387
	Leg (g)	na	na	na						1.566±0.981	1.835±1.382	1.707±1.238	1.244±0.743
	Total (g)	$1.68_{3,37}$	0.19	0.05						9.979±5.783	9.117±7.463	12.716±10.499	5.038±2.942
Liver fat mass	Percentage (%)	$3.91_{4,36}$	0.01	0.23	**0.010**	*	*	Sex*Size	0.085	6.38±4.27	3.35±2.42	7.01±3.49	3.82±1.84

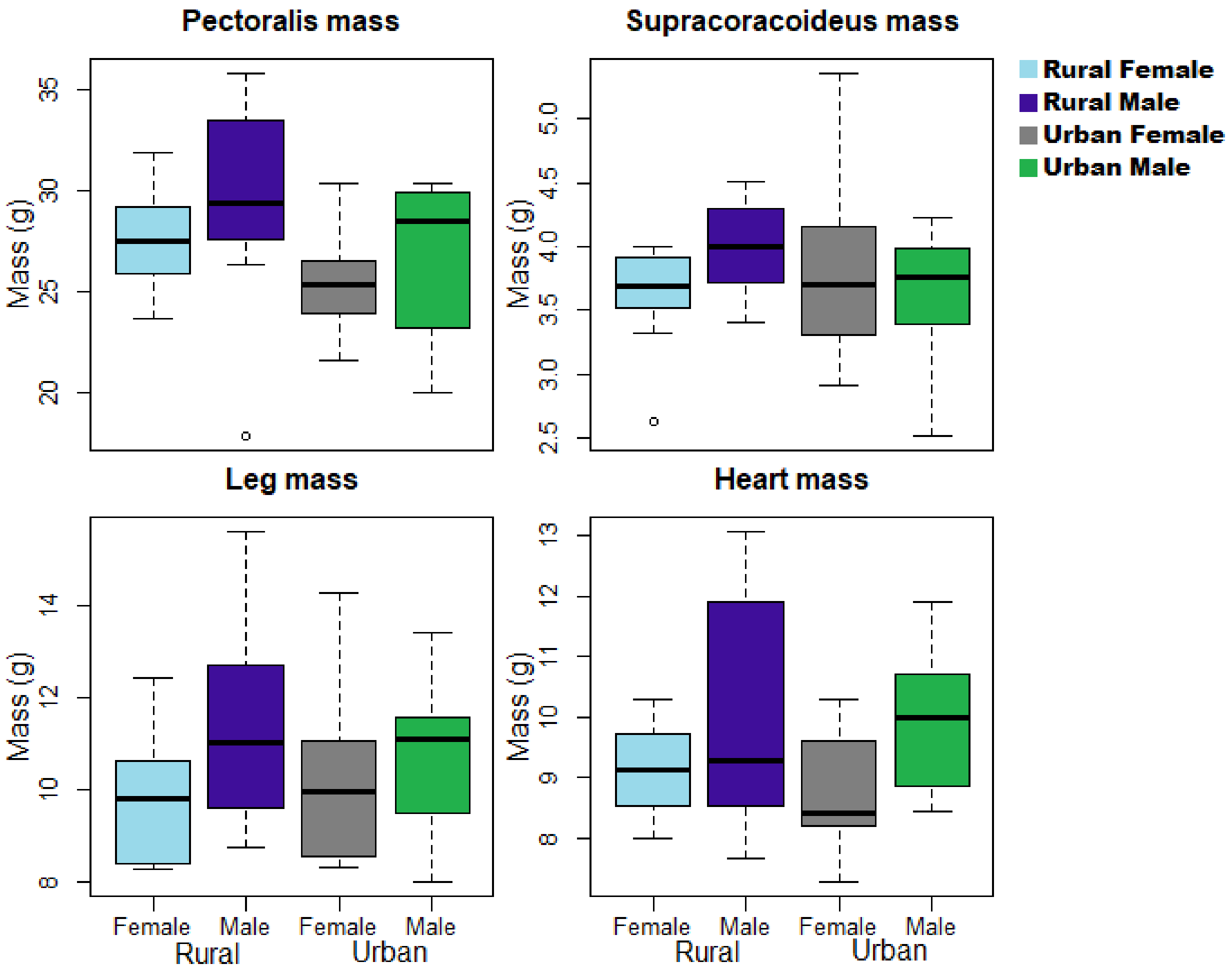

Figure 3.3. Dried mass of skeletal and cardiovascular muscles of rural and urban Mallards. Pectoralis major masses differed significantly with habitat; heart mass differed with sex. Sample sizes from left to right=12, 8, 11 and 10. Boxes enclose the 25th–75th percentiles and the median, whiskers extend to the range, or to 1.5 times the interquartile range with circles showing outliers outside this range.

Digestive organs

Body size related to organ size for a range of digestive organs (liver length, proventriculus length, gizzard mass and length, small intestine mass and length, large intestine mass and caeca mass and longer caecum length), but habitat (urban versus rural) also affected gizzard mass and size (larger in urban birds) and caeca lengths (longer in urban birds) (Table 3.1; Fig. 3.4).

Gizzards were also larger in males (width of gizzard and thickness of the gizzard muscle), as was the length of the shorter caecum. Variation in liver mass, pancreas mass, proventriculus mass and large intestine length were not explained by the factors tested. The spleen varied in complex ways with habitat, sex and size, due largely to urban males having light spleens (Table 3.1). There was also an interaction in liver length, which increased less with size in males than females.

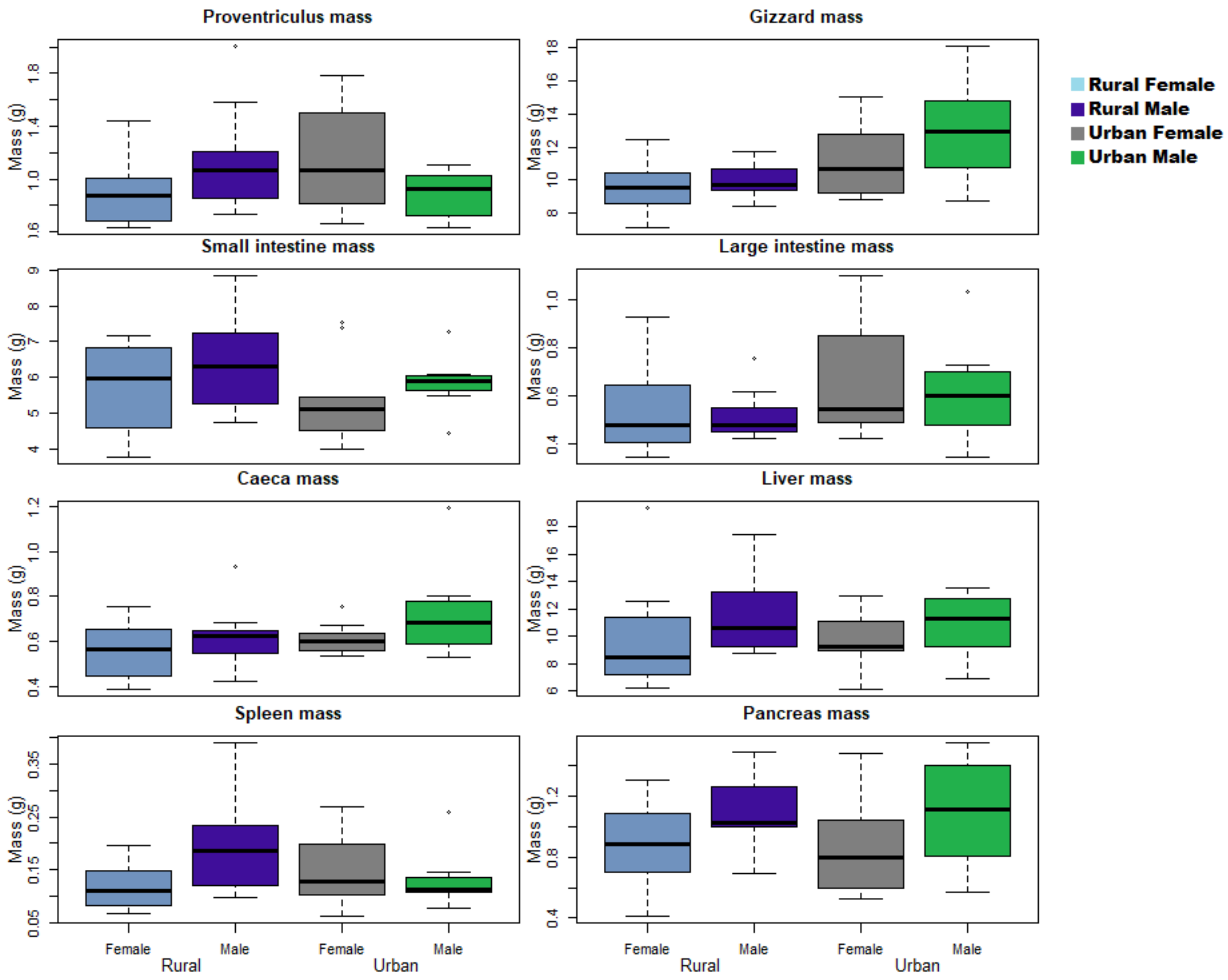

Figure 3.4. Organ masses in urban and rural Mallards. Masses represent the dry mass of each organ. Contents of organs removed prior to drying. Sample sizes are as in Fig. 3.3.

Fat deposits

Variation in fat masses was poorly explained by the models, with only a lower level of abdominal fat in urban birds being detectable (Table 3.1), though the general pattern was for urban birds to have lower fat levels (Fig. 3.5). Urban birds on average had around half the fat content in their livers compared to rural birds (Fig. 3.5).

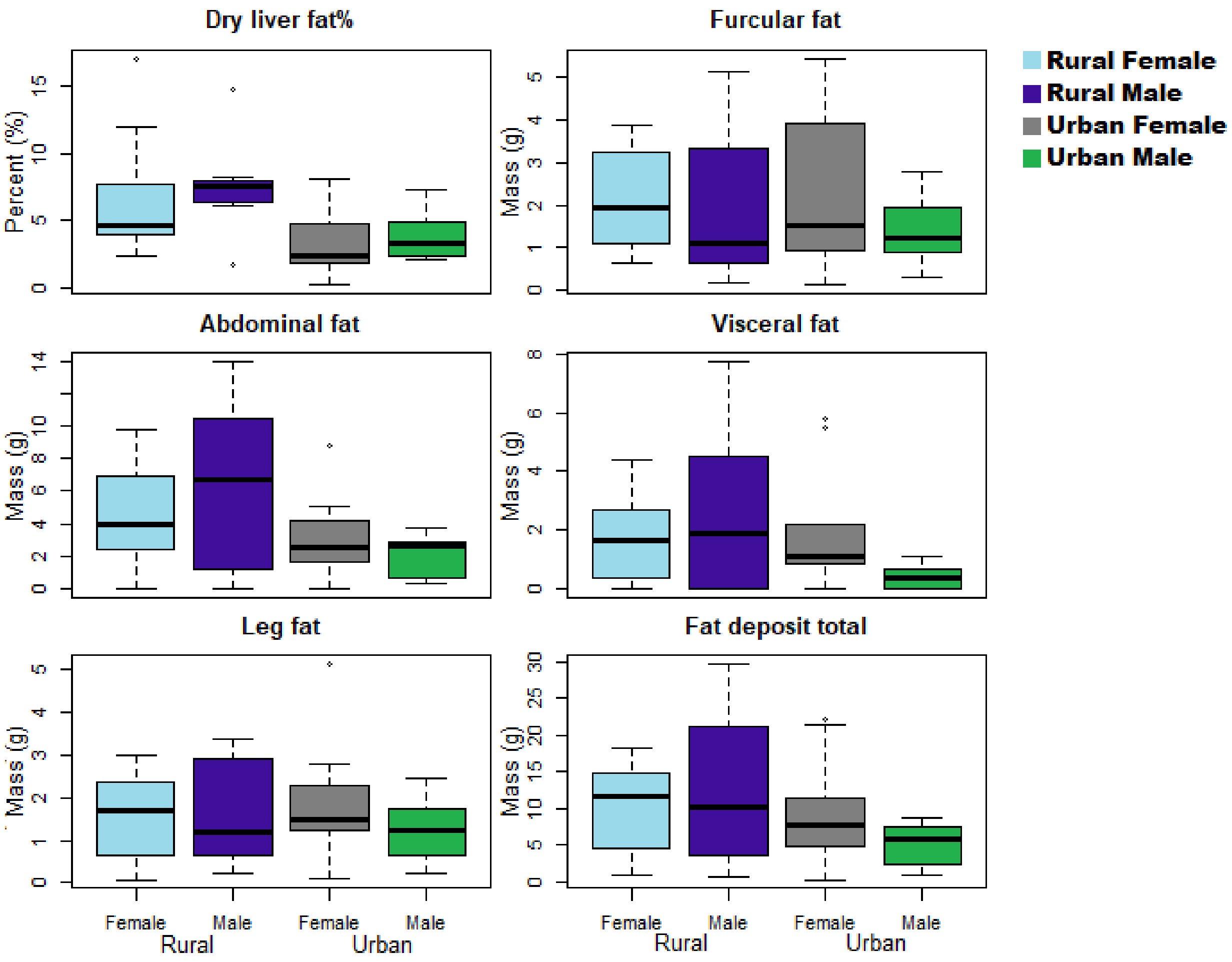

Figure 3.5. Fat masses in urban and rural Mallards. Masses represent the dry mass of fat removed from each region (note that leg fat was from only the right leg). Fat deposit total is the sum of the mass of the furcular, abdominal, visceral and right leg fat deposits. The per cent fat in the liver represents chemically extracted fat as a percent of the liver dry mass. Sample sizes are as in Fig. 3.3.

Liver histology

There were no significant differences in hemosiderin (χ2, df=3, P=0.398) or lipid (χ2, d =3, P=0.412) deposits in the liver of rural or urban ducks. A high proportion of Mallards (13/23 rural, 12/17 urban) had a lipid deposit score of 0, while hemosiderin deposits were fairly evenly spread across all scores for both urban and rural Mallards (Fig. 3.6).

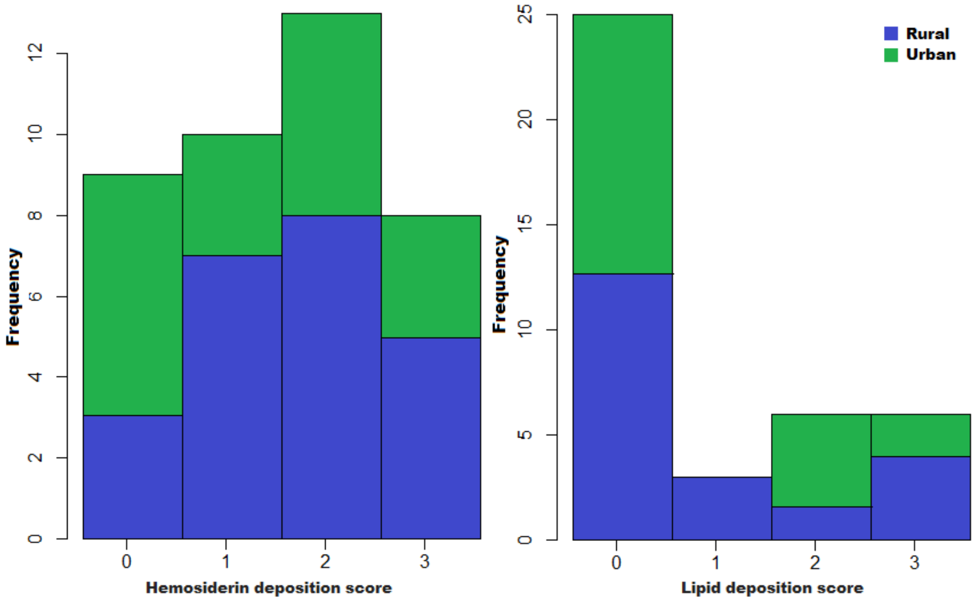

Figure 3.6. Haemosiderin (left) and lipid (right) deposition in the liver were assigned scores dependant on the severity of their presence in the hepatocytes: 0 = none, 1 = some, 2 = moderate, 3 = excessive.

Gut parasites

Rural ducks had higher mean parasite count (2.47 parasites) than urban Mallards (0.94 parasites), although formal statistical comparison was not possible due to there being very few individuals with gut parasites and generally low gut parasite counts. Differences between average parasite counts of rural and urban Mallards were heavily influenced by two rural individuals who had high worm counts in comparison to all other individuals (Fig. 3.7). One urban Mallard had a proventricular cyst that was filled with adult nematodes.

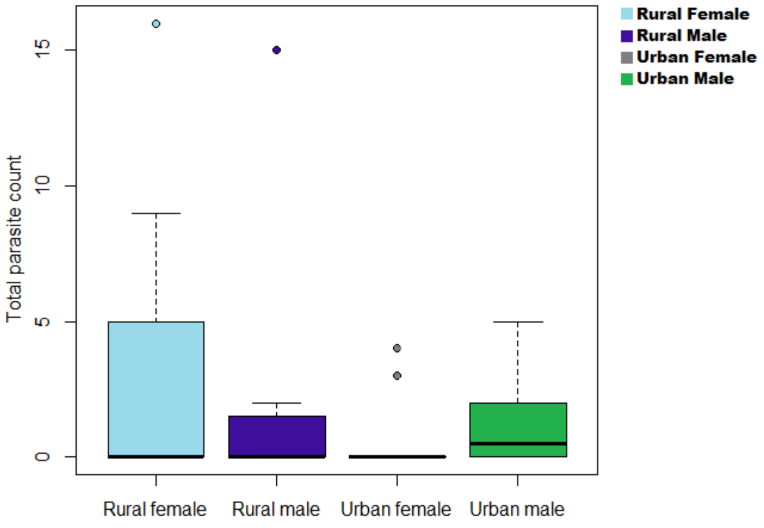

Figure 3.7. Total endoparasites in the small intestine, large intestine and caecum. Sample sizes are as in Fig. 3.3.

Discussion

The focus of this study was to determine the impacts that an urban lifestyle, in particular, anthropogenic feeding has on the physiology of Mallards. This was achieved by making comparisons of gross morphological differences in body composition, and other health-associated aspects between Mallards in a modified environment with high levels of feeding by humans, and Mallards in rural habitats. It was predicted that urban Mallards would have smaller digestive organs as it was expected they would have lower levels of dietary fibre in their diets compared to urban birds due to the availability of anthropogenic food. Additionally, urban Mallards were expected to have larger masses of fats due to the high caloric value of anthropogenic food and not requiring much energy expenditure to obtain food. While this study could not conclude that wildlife in and of itself was the sole cause of any differences found between urban and rural Mallards, some of the finding support that the urban lifestyle results in changes in body composition.

A trend seen throughout all muscles and organs was that these increased with body size whereas fat deposits did not. It is not surprising that muscle mass increased with bodyweight given that larger muscles are needed to support the locomotion of larger individuals (Lindstrom et al., 2000). Indeed, the mass of the leg muscles increased with respect to size in this study, as did the mass of the pectoralis major, the main powered flight muscle (Biewener, 2011). Interestingly, the pectoralis major was larger in rural Mallards than in urban Mallards despite no difference in overall body weight or size between the groups, even when sex was accounted for. Perhaps this is because rural Mallards have larger home ranges and therefore greater flight requirements than do urban birds. In the USA, Varner et al. (2014) found that the medial home range upwards of rural Mottled ducks (*Anas fulvigula)* was more than 65 times larger than urban ducks. Therefore, rural ducks probably forage over larger areas and spend more time flying than do urban ducks (Møller, 2009; Bengtsson et al., 2014), thus requiring larger masses to travel such distances.

The digestive organs of birds are notable for their phenotypic flexibility (Piersma and van Gils, 2011), and respond to the kinds of foods available in an individual’s environment. Dietary fibre is known to have profound effects on the function and length of avian GI tracts (Clench & Mathias, 1995; Battley & Piersma, 2005; Durant, 2013). Foods high in dietary fibre have low rates of digestibility. The lengthening of the intestine allows for a greater quantity of food to be accommodated and therefore processed, thus increasing digestive efficiency (Moss, 1989). Additionally, a large gizzard mass is required to provide the mechanical forces required to shear the bonds of structural fibre, thus many grazing species possess these characteristics in their gizzard (Moore, 1998a). Given that the diet of urban ducks includes a substantial contribution of anthropogenic foods, I expected that urban Mallards would have shorter GI tracts than rural Mallards (as anthropogenic foods would not need hindgut fermentation to break down the complex bonds between molecules: Svihus et al. (2013)) and smaller gizzards (due to lower levels of indigestible fibre in the urban diet).

Instead, I found the opposite: urban Mallards had larger and more muscular gizzards in addition to having elongated caeca compared to rural Mallards. Ultimately, as urban Mallards had larger gizzards suggests that urban Mallards have a high intake of dietary fibre or additionally forage on other food items that require mechanical force to process than expected (Miller, 1975). However, other factors such as hardness of food have been also shown to increase the size of gizzards (Richardson & Wooller, 1990). I observed Mallards at the Victoria Esplanade, during this study, foraging on acorns which are likely the causes of their enlarged gizzards. The gizzard masses of Red Knots (*Calidris canutus*) have been observed to increase by 147% within 6.2 days when hard food items are introduced to the diet (Dekinga et al., 2001), thus Mallard's gizzards may be responding to the hardness of the acorns. This notion is supported by urban Mallards having thicker gizzard muscles as mechanical pressure produced increases in portion to gizzard muscle thickness (Moore, 1998a). Additionally, as urban Mallards are not flying greater distances than their rural conspecifics (Varner et al., 2014), they may not need to reduce their gizzard size, thus total body weight, to facilitate flight (Moore, 1998a).

High food intakes in urban Mallards, from either anthropogenic or natural sources, would result in lengthening of the GI tract (Miller, 1975, 1976; Karasov, 1996). However, in my study, the size of the GI tract typically increased with body size and not between urban and rural environments. This makes sense as a larger GI tract is required to meet the metabolic demands of a larger body (Miller & Eadie, 2006). Although, there will be an increase in basal metabolic cost to maintain a larger GI tract (Battley & Piersma, 2005), which in turn would influence the total excess energy an individual will have to convert into fat. Although in this study many digestive organs increased in size in proportion to body size, some digestive organ sizes differed between rural and urban environments, those organs being the gizzard and caeca.

The caeca have multiple functions in birds including microbial fermentation, water and nitrogen absorption and immunosurveillance (Klasing, 1998). High intakes of dietary fibre in the diets of Mallards can also affect caeca length (Miller, 1975, 1976; Kehoe et al., 1988; Clench & Mathias, 1995). I found that urban Mallards had larger caeca that rural Mallards. It is unlikely that urban birds had a high-fibre diet (Ottoni et al., 2009), and an alternative explanation for their longer caeca is that they could play a greater role in immunosurveillance in the high-density urban environment where the risk of disease is greater (Clench & Mathias, 1995: Murray et al., 2016). Additionally, urban Mallards have been found to have higher levels of fungal diversity than rural Mallards (Meissner et al., 2015). Although relatively few individuals were found to have gut parasites present, one of the urban Mallards was found to have a proventricular cyst that was filled with adult nematodes. Therefore, the elongation of caeca could be the result of the continuous immune response to individuals living in a habitat where contact with different pathogens is common (Clench & Mathias, 1995). Parasite infestation is also known to influence fat deposits of individuals, as the uptake of nutrients and energy from food ingested will divert to the parasite from the host (Brown et al., 1995), reducing the total energy available to the host species.

As anthropogenic foods such as bread are typically high in carbohydrates (Friedman, 1996), and thus energy, it would be expected that urban Mallards would have large fat deposits due to excessive energy being converted to fat. However, there were no significant differences in fat deposits between the two groups. Urban birds having poorer body condition than their rural conspecifics has also been seen in the American White Ibis (*Eudocimus albus*) (Murray et al., 2018) and House Sparrow (*Passer domesticus*) (Liker et al., 2008).

This could be a result of the predictable nature of the anthropogenic food supply meaning that birds do not need substantial fat stores as an energy buffer. Males tended to dominate food hand-outs, and the lower fat levels in urban males could mean that they, in particular, need less of an energetic buffer than females do. An alternative explanation can be explained by the “credit card” hypothesis (Shochat, 2004). In this, the predictable food supply and low predation risk at urban sites allows excessively high populations to congregate, despite them exceeding the local carrying capacity. This results in many birds being in poor condition, with just a few ‘winners’ expected to dominate the food resources, and urban birds would have poorer body condition than individuals in a more natural environment (Liker et al., 2008). It is suggestive that the leanest birds in our sample were urban males, implying that they might face the largest nutritional deficit.

Although urban species have lower predation risk, thus associated stress caused by predation, the urban environment is just as relatively stressful on urban species as rural environments are on their rural counterparts (Ditchkoff et al., 2006). Stress is known to cause weight loss in the long-run as glycogen stored in the liver is broken down into glucose, thus drawing from the individual's energy reserves (Siegel, 1980), which could be why urban individuals in this study only had lower proportions of fat in their liver than rural Mallards. Additionally, when Mallards were captured for this study rural and urban Mallards had just undergone the physiological process of moulting their flight feathers (Sheppard, 2017). Moulting is physiologically expensive with Mallards having an estimated 30% increase in their basal metabolism to meet the energy required to forego a complete moult (Fox et al., 2013). Mallards meet this increase in metabolic cost by drawing from their fat stores (Pehrsson, 1987). This could be the reasoning why I found no difference in most discrete body fats in individuals in both urban and rural environments.

As individuals had just undergone a moult, this could explain why I saw low levels of lipid deposition (score of 0) in liver histology of 62.5% of individuals in this study. Due to the high proportion of the urban and rural population scoring 0 for their lipid deposition, there were no significant differences in lipid deposition between the two environments. Therefore, the proportion of liver mass contributed by the storage of fat maybe not a reliable indicator of total fat stored within the liver. Rural individuals were found to have nearly double the proportion of their liver mass being fat than urban birds, despite little variation in liver mass between the two environments. It is also entirely possible that the parts of the liver that were used for histology are not the primary sites for fat storage in the liver unlike deposits of hemosiderin. Much like lipids deposition, there were no significant differences in the quantity of hemosiderin deposition between the two environments. It was predicted that due to the intensification of agriculture practises being a prominent contributor to metals in soils and water (Mance, 2012), rural Mallards would have greater levels of hemosiderin than urban Mallards. In this study, there were more rural Mallards (5) than urban Mallards (3) that had a score of 3 for their hemosiderin deposition, but, this could possibly due to rural Mallards having a larger sample size. Nevertheless, levels of hemosiderin were consistent across all scores for both urban and rural Mallards. Therefore, I cannot say if an urban lifestyle for Mallards will have detrimental health effects caused by the build-up of iron in their liver (Cork, 2000).

Although differences in GI physiology and fat deposits between urban and rural Mallards were found in this study, the results were not as predicted. Prior to conducting this study, it was predicted that urban Mallards would have a truncated GI tract (most notably in the gizzard and caeca) and heavier fat deposits than rural Mallards. However, in this study urban Mallards had larger and more muscular gizzards, potentially due to them foraging on harder food items, such as acorns, they had been observed foraging on. It was also expected that urban Mallard should have a shorter caecum than rural Mallards, as an elongated caecum wouldn't be needed for hindgut fermentation to break down anthropogenic food low in fibre, however, this was not the case. The caecum is a complex organ with many functions outside of digestion and many factors can influence the size of the organ. Therefore, it cannot be confidently concluded from this study that the dietary differences between urban and rural Mallards are the sole reasoning of the elongation of the caecum. Finally, with anthropogenic food being high in energy and easily foraged, it was expected that urban Mallards would have excessive reserves of fat throughout their body compared to their rural counterparts. However this was also not the case, there were no differences in fat reserves of urban and rural Mallards.

Chapter 4

Synthesis, discussion and conclusions

Chapter 4: Synthesis, discussion and conclusions.

This study intended to explore the effects of urbanisation, though wildlife feeding, on the feeding ecology and physiology of Mallards (*Anas platyrhynchos*). As more humans move into urban areas (Cox & Gaston, 2016), their main engagement with nature is through wildlife feeding (Jones, 2011b). The practice of wildlife feeding is multifaceted, and aspects of wildlife feeding needed to be explored both the human and receipt species (in this case Mallards) perspectives to get a better understanding of the practice. Although similar studies have been conducted exploring the participation rates of wildlife feeding (see Rollinson et al., 2003; Chapman & Jones, 2009; Galbraith et al., 2014) in Australasia, this is the first study to my knowledge that explores the quantitative degree of anthropogenic food being offered to Mallards through wildlife feeding in a park.

The contents of this thesis were split into two major parts. In Chapter 2 I explored the behaviour of humans and Mallards engaging in wildlife feeding at the Victoria Esplanade, Palmerston North, New Zealand. The main aspects of the human side of wildlife feeding I was interested in were when people were engaging in wildlife feeding, what food and how much was being offered, and who was feeding the Mallards. From the Mallard perspective, I wanted to know how Mallards responded to the influx of food on offer and to see how they utilised the natural resources available in the Victoria Esplanade and surrounding area. From this information, I obtained insight into the urban diet of Mallards which is lacking in the literature. This information was pivotal in explaining some of the physiological difference between Mallards in an urban versus a rural environment in Chapter 3.

Physiological differences of interest were the gastrointestinal tract, flight muscles and discrete fat deposits. In addition to assessing physiological differences in Chapter 3, I also assessed factors such as total gastrointestinal endoparasites and the abundance of haemosiderin and lipids within the liver, to identify any potential health impacts on Mallards living in an urban environment. Many of the differences I found contrasted with what was expected. However, when considering the lifestyle of urban Mallards and the level of wildlife feeding occurring at the Victoria Esplanade, most of the findings were explicable. The findings in these studies suggest that the effects of wildlife feeding on the foraging behaviour and physiological health of Mallards in this population are minimal. However, this conclusion may be situation-specific, and these results provide a basis for comparison with future research that may be conducted in other locations.

The human dimension of wildlife feeding

One of the most astonishing results of this study was the enthusiastic participation from members of the public to have their food items weighed. I had expected some hesitance about participating due to the local council installing a sign trying to prevent the feeding of bread. However, there wasn't a single instance of any group refusing to have their food weighed. Many individuals were interested in the study and wanted to learn more about the possible negatives of wildlife feeding or why feeding Mallards bread was "bad" for them. It was not surprising to see that bread item made up 83.8% of the 62 kg of food offered to the Mallards, as Galbraith et al. (2014) found similar rates in their survey of New Zealand households.

The main study site of wildlife feeding explored in this study was a public park, however, wildlife feeding commonly occurs in households' gardens. Galbraith et al. (2014) study into participation rates of New Zealand households engaging in wildlife feeding showed that 46.6% of households engaged in the practice in their own gardens. From my observations, participation rates of wildlife feeding at parks are lower than for backyard feeding. Galbraith et al. (2014) found that the likelihood people would engage in wildlife feeding their backyard increased with age, whilst in this study, it appears as though it is younger adults with children engaging in wildlife feeding in the park. This suggests that the motivations behind feeding may differ between the park and backyard feeding. Backyard feeding is a convenient activity that can be rewarding for people who spend a lot of time at home. Park feeding may be a welcome opportunity for family groups to get out of the house and into a semi-natural environment, often with the added benefit of a playground nearby.

A great deal of study has been conducted exploring the connection between engagement with nature and the benefits it has on human mental, physical, and social health (Keniger et al., 2013; Cox & Gaston, 2016). The nature-deficit disorder is the belief that humans, primarily children, are not spending enough time outside and that this is resulting in diverse behavioural problems, most commonly Attention Deficit Hyperactivity Disorder (ADHD) (Louv, 2008). Children that spend at least 1 hour per day outside ("green time") appear to have reduced symptoms of ADHD (Driessnack, 2009). Therefore, parents who bring their children to their local parks to engage in wildlife feeding are passively contributing to this recommendation of daily green time. However, it is not only children that benefit whilst engaging in nature. Many studies have shown a decrease in anxiety, mental fatigue, stress, etc., (see Keniger et al. (2013) for more details) in adults who regularly engage with nature. Thus, wildlife feeding has many benefits beyond just assisting wildlife through tough conditions and being an activity for families to do together on the weekends. If the practice is to continue participants need to be aware of any negative impacts that their contribution to wildlife feeding may have on recipient species.

The Mallard dimension of wildlife feeding

One of the most commonly used arguments about wildlife feeding practises being "dangerous" to wildlife is that individuals are developing dependencies on humans feeding them. However, my results indicate that not all Mallards of the Victoria Esplanade population rely purely on anthropogenic food. Mallards are opportunistic omnivores and thus will change how they forage in response to what foods are available. Throughout the day, when wildlife feeding is not occurring, on average 9.7% of this population is foraging on naturally available foods (i.e., grass and acorns). When anthropogenic food becomes available, the vast majority of the population (78.3%) takes advantage of the opportunity. This dramatic increase isn't surprising when considering that anthropogenic food is not always readily available in this environment and has a high energy intake to energy expenditure return. The high competition that occurs to obtain anthropogenic food could possibly be the reason why some individuals (2.2% of the population) still forage on naturally available foods even in the presence of wildlife feeding. Further evidence that this population of Mallards do not spend their entire lives at the duck pond waiting to be feed is that GPS-tracked individuals were seen foraging in the surrounding area eating acorns, and in one case, documented spending time in the Manawatu River.

Although urban Mallards are foraging on naturally available foods, there is strong evidence to suggest that differences between the two environments have an impact on the physiology of Mallards. There was a significant difference between rural and urban Mallards in the size of the gizzard and the length of the caeca, in addition to differences in major locomotion muscles, and to an extent, some minor differences in the deposition of fat. Although many of these differences could be explained by the lifestyles of Mallards from each area, the outcomes found were the opposite of what was expected.

The two most notable digestive organs showing a difference in size between the two environment types were the gizzard and caeca. Due to the low dietary fibre content in anthropogenic foods, it was expected that urban Mallards would have smaller gizzards and shorter caecum. However, I found that urban Mallards had larger and heavier gizzards than their rural conspecifics. This difference in gizzard size is likely to be caused by Mallards foraging on the assortment of acorns and other hard seeds that are naturally present in the Victoria Esplanade. Due to the robust nature of acorns, large mechanical pressures are required to break open the seed and thus, a larger gizzard is required to produce the necessary force needed.

In addition to urban Mallards having a larger gizzard, I found that they also possessed longer caecal lengths than rural Mallards. There is a strong correlation between the dietary fibre content of the diet and caecal length for bacterial fermentation of cellulose, which birds cannot break down. Therefore, I expected longer caeca in rural birds if they were eating a higher grass component than urban birds were. However dietary fibre in the diet may not be the driving force for the differences seen between the two environments in this study. The caecum has immunosurveillance properties and urban Mallards have been found to have levels of microbial diversity than rural Mallards (Meissner et al., 2015). Therefore, the observed caecal lengths may be the result of continuous immune response to individuals living in a habitat where contact with different pathogens is common (Clench & Mathias, 1995).

Another surprising observation made was there were no noticeable differences in most fat deposition between the two environments. It was expected that urban Mallards would have greater fat deposits than urban birds, due to anthropogenic food, primarily bread, being high in carbohydrates and thus energy. However, I found that urban Mallards had significantly less abdominal fat. From observations made of people offering Mallard's bread, assuming each Mallard got an equal share, they would receive 5.9 g of bread which is equivalent to approximately 59.5 Kj per feeding event. This means that at least 8.5 feeding events per day would be needed for males and 6.8 for females, just to meet their resting metabolic needs, both of which are higher than the expected 6 daily feeding events measured from observations. Thus, Mallards are not receiving adequate energy from wildlife feeding alone which could contribute to why urban Mallards had lower body condition than expected. Additionally, as there is a regular influx of anthropogenic food, urban Mallards may also not need to build up fat restores due to high energy food being available regularly.

Limitations

Although the attachment method of the GPS units was successful in a pre-trial to this study, the application of GPS tracking Mallards was problematic in the field. Issues arose in firstly capturing Mallards of a suitable weight and moult progression for the GPS units. Secondly, many individuals preened their tail feathers in response to the GPs unit attached to the extent of removing the entire central feathers (thus losing the logger). Finally, as GPS loggers were used instead of transmitters, recapture of the Mallard and recovery of the GPS unit was essential for data collection. Many individuals that had a GPS unit attached were either never re-sighted or were found without the GPS unit still attached. Therefore, only two Mallards were successfully tracked in this study. The use of harnesses to attach the GPS loggers to the Mallards was considered as they have been successfully used in other trials (see Wheeler (1991), but were not used in this study due to animal ethical reasons. Additionally, the use of GPS transmitters was also considered but due to the costs associated with such devices, and the monitoring program intending to be short-term, this method of monitoring was not feasible for a study of this size.

While the method of submersing dried livers into petroleum ether to extract fat content was successful, the use of a soxhlet apparatus would have been to be beneficial in this study and allowed me to extract fat from all organs. The constant need to refresh the petroleum ether the livers were submerged into was an inefficient way to use the solvent. With the use of a closed system soxhlet apparatus less petroleum ether would have been required, thus additional organs or muscles could have their fat content assessed. As fat is stored not only in just discrete deposits and the liver but in muscle and bone, assessment of these would give insight into overall body fat stores. Additionally, if I had taken blood samples from the Mallards after capture, I could have accessed lipid in the blood or hormones that affect the storage or mobilisation of fats.

Although relatively few individuals were found to have gut parasites present, this is possibly due to the technique and inexperience of collecting and identifying parasites. Additionally, egg counts of parasites were not conducted as well as any screening for microparasites. Therefore, it is likely that the total observed endoparasites in Mallards were severely underrepresented in this study.

Future research

From the two Mallards, I was able to successfully track I saw that the Mallards are utilising the surrounding bush and Manawatu River near the Victoria Esplanade. With diverse habitats within a 2 km proximity to the Victoria, Esplanade Mallards may be offsetting their expected diet of anthropogenic-focused foods with naturally available foods. As Palmerston North is not heavily urbanised, Mallards have relatively easy access (1 km flight) to many sources of natural foods, therefore, they are likely obtaining foods that other Mallards in more heavily urbanised areas could not access. Therefore, it would be worth exploring if there are any noticeable differences in populations where access to natural foods is severely limited.

Another area of interest that could be explored is if urban Mallards are more likely to be reliant on anthropogenic foods throughout the year. From population counts in this study, I found there was seasonal variation in the total number of birds present. The difference in population size was attributed to the possibility that the population size was greater in the summer, due to moulting (and hence flightless) individuals being restricted in the area they could forage within for food. Additionally, the population could have included juvenile Mallards from the previous breeding season. However, I have no evidence to suggest that the above explanations are what is occurring in this population and further exploration needs to be conducted to explain why there is a larger population size during the summer months.

It would also be interesting to see the range of different foods that urban Mallards naturally forage on throughout the year. As Mallards are opportunist omnivores their diet is typically a reflection of the availability of food within their environment. Since different plant species flower and seed at varying times of the year, it could be worth exploring how environments with varying plant diversity influence natural foraging behaviour. If natural food was available in abundance throughout the year, would this impact and challenge the belief that urban Mallards are dependent on anthropogenic food? Furthermore, the energy requirement of individuals varies throughout the year. Breeding, moulting and harsh weather conditions are known to increase the metabolic rate of individuals. Does the increase in energy demands result in individuals changing the kinds of food they forage on, or do they increase their foraging effort to meet these metabolic needs? This is an area that needs further exploration and would prove beneficial to the population management of urban wildlife and city planning to create more green spaces for humans and wildlife to coexist.

Conclusion: Is wildlife feeding bad?

From the results of this study, I found no obvious health concerns for Mallards foraging on anthropogenic food at the level of wildlife feeding occurring at the Victoria Esplanade. I have strong evidence to suggest the Mallards at the Victoria Esplanade are not entirely reliant on anthropogenic food to meet their metabolic needs. The occurrence of wildlife feeding was less than expected, such that there would be insufficient anthropogenic food being offered to the Mallards to meet their resting metabolic needs. Mallards are not building great fat reserves on anthropogenic food, but nor are they malnourished due to reliance on insufficient food supply. Additionally, while an excess of anthropogenic foods can result in the development of angel wing, and historical occurrences of this condition have been identified in this population no individuals were identified with this condition during my study. At the Victoria Esplanade, which provides a diverse set of habitats near the urban fringe, wildlife feeding is currently at a level that does not generate discernible ill effects in Mallards.

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Appendix 1

Nutritional composition of commercially sliced bread offered to Mallards

Appendix 1: Nutritional composition of commercially sliced bread offered to Mallards

Loaf weight, price and nutritional value per 100g of commercial sliced bread brands observed being offered at the Victoria Esplanade. Bread brands are listed in ascending price.

Brand	Bread Type	Price per Loaf ($NZD)	Quantity (g)	Energy (Kj)	Protein (g)	Total Fat (g)	Saturated Fat (g)	Carbohydrate (g)	Sugar (g)	Dietary Fibre (g)	Sodium (mg)
Value	White	$0.99	600	990	8.7	1.9	0.4	43.9	3.4	3.3	400
Value	Wholemeal	$0.99	600	958	10.1	2.2	0.4	38.9	3.2	5.2	360
Homebrand	White	$1.00	600	1040	8.9	2.2	0.5	46.4	3.0	2.5	410
River Mill	White	$1.75	600	1000	8.8	1.9	0.4	44.0	3.5	3.2	390
River Mill	Wholemeal	$1.75	600	960	10.1	2.2	0.4	38.9	3.2	5.2	360
Gold Max	White	$2.00	550	1000	7.8	1.4	0.3	47.1	2.4	2.2	420
Gold Max	Wholemeal	$2.00	550	1000	8.5	1.6	0.3	44.9	2.5	4.0	420
Nature's Fresh	White	$2.95	700	1060	9.1	2.2	0.2	48.4	3.0	3.5	390
Nature's Fresh	Wholemeal	$2.95	700	1020	9.1	2.3	0.3	44.4	3.0	3.5	365
Tiptop	Multigrain	$2.99	700	986	10.1	2.2	0.4	40.8	1.8	4.8	378
Tiptop	White	$2.99	700	1050	8.1	2.1	0.4	48.2	2.4	2.4	440
Molenberg	Multigrain	$3.19	700	1040	10.7	4.2	1.6	39.1	2.8	5.2	400
Molenberg	White	$3.19	700	930	9.1	2.0	0.8	38.2	2.6	6.5	375
Ploughmans	Multigrain	$3.29	750	1060	8.5	3.2	0.5	43.4	2.7	4.8	400
Ploughmans	White	$3.29	750	1060	8.0	2.1	0.3	48.2	3.4	2.8	400
Ploughmans	Wholemeal	$3.29	750	1030	9.5	2.2	0.5	43.0	2.7	6.7	400
Quality Bakers	White	$3.29	450	1052	8.2	1.9	0.4	48.9	3.0	3.2	453
Vogels	Multigrain	$3.99	750	910	9.0	1.0	0.3	40.4	3.2	4.1	425