Duckling survival and habitat selection of brood-rearing mallard *(Anas platyrhynchos)* females in Southland, New Zealand

Erin Garrick

A thesis submitted for the degree of

Master of Science

In

Wildlife Management

at the University of Otago, Dunedin

New Zealand

2015

Abstract

Southland has been long recognized as a productive area for mallard ducks *(Anas platyrhynchos)* in New Zealand. Populations have declined in recent years, and these declines have coincided with an increased intensity of conversion of sheep and deer farms into pastoral dairy farms. Sheep and deer farming comprise many short-grass pastures during the waterfowl breeding period, whereas dairy cattle are typically rotated around pastures in a manner that results in many long-grass pastures that are intensively defoliated by grazing every few weeks. Some critics have blamed dairying for the decreases in mallard productivity. In 2014, I investigated environmental factors and female characteristics affecting mallard duckling survival, including: pasture type (long or short grass), percent dense nesting cover within a buffer of the areas used by broods, presence of ephemeral water, distance to the nearest permanent water source, distance to the nearest anthropogenic structure, brood size, egg volume, female age, date of hatch, precipitation, duckling age, and average distance moved from the nest site. I monitored 438 ducklings from 50 radio-marked females to 30 days post hatch. I modeled ragged telemetry data using the nest survival module in Program MARK and evaluated model fit using Akaike's Information Criterion adjusted for small sample size and overdispersion ($QAIC_c$). Duckling survival was unaffected by pasture type, but increased with duckling age ($\beta = 0.05$, 85% CI = 0.02 – 0.08), the presence of ephemeral water ($\beta = 0.58$, 85% CI = 0.15 – 1.01), and with greater distance from the nearest anthropogenic structure ($\beta = 0.28$, 85% CI = 0.02 – 0.54). Survival was lower for broods of second year (SY) females than for broods of after second year (ASY) females ($\beta = -0.52$, 85% CI = -0.90 – -0.13), in areas with more dense nesting cover ($\beta = -0.37$, 85% CI = -0.60 – -0.15), and when ducklings moved, on average, greater distances ($\beta = -0.33$, 85% CI = -0.56 – -0.10). Cumulative 30 day duckling survival ranged from 0.11 (85% CI = 0.07 – 0.15) for ducklings of SY females without ephemeral water present to 0.46 (85% CI = 0.41 – 0.51) for ducklings of ASY females with ephemeral water present. Compositional analyses indicated females selected for dense nesting cover at both the landscape scale (30 km^2) and within habitat corridors used by their broods. A resource selection function revealed brood-rearing females preferred dairy pastures within areas used by their broods, areas further from anthropogenic sources, and dense nesting cover. My results show that duckling survival is low in Southland relative to estimates using similar methods from North America. Further, dense nesting cover is selected for by brood-rearing females, but translated into lower duckling survival. Narrow, linear, small patches of dense nesting cover could support a greater abundance of predators, or enable greater foraging efficiency of predators. Mallard females might be selecting habitat to maximise another aspect of their life history (e.g., adult female survival, nest success) at the expense of duckling survival.

Acknowledgements

Funding was provided by the New Zealand Fish and Game Council. I especially want to extend a massive thank you to my external advisor Courtney Amundson, for her invaluable advice and direction. I am sure without her help I would still be struggling along in the early stages of the analysis. I would also like to thank my supervisor, Phil Seddon, who has provided support and encouragement. Luke Easton, thanks for all the long yarns over cups of tea about various MSc student sufferings! Much appreciation for those who read and provided comments on my drafts; I owe you all a huge thank you - I know my writing needs a bit of polishing! Dorian Garrick, Matthew Garrick, Matt McDougall, David Klee, Zane Moss and Phil Seddon. Jenn Sheppard, thanks for your help getting started and with various training protocols. Thanks also to both Jane McMecking and Simon Allard for my myriad of ArcGIS questions.

Southland never failed to deliver: through sideways rain and hail, two enthusiastic field technicians, Phil McCartney and Taylor Davis collected a huge amount of data. Many other volunteers offered their time to help with brood observations and additional support was received through both Otago and Southland Fish and Game staff: Jacob Smythe, Stu Sutherland, Bill Jarvie (and Ollie the dog), Maurice Rodway, Zane Moss, Cheryl Mason, Ann Heffernan, Cohen Stewart, Morgan Trotter, Helen Keeling and Ian Hadland. Thanks to all the landowners (too numerous to name) who allowed us to wander through their property in search of marked females, their broods, and nests. This project would not have been able to be carried out without your assistance.

Lastly, I would like to thank my family for their encouragement, inspiration and support. Thanks for raising me to respect and value the great outdoors and all the

wildlife that inhabit it. I never thought I'd be chasing ducks in sideways rain for six months in Southland, but I enjoyed every minute of it!

This thesis is dedicated to 'Maverick' – my shadow throughout the busiest part of the field season. She hatched on some data sheets on top of the kitchen table, kept me sane while entering data into the nights, and her endless dabbling at the computer keys provided much entertainment. My hard drive is filled with many fond memories and video clips of her traversing through all sorts of terrain! An arrow only flies as fast as the ambition behind it….

Erin J. Garrick

Meet Miss 'Maverick' at one day of age.

Table of Contents

Table of Figures

Table of Tables

Marked mallard females with their broods in long-grass dairy pasture (top) and short-grass sheep pasture (bottom) in Southland, New Zealand, 2014.

Photos courtesy of Phil McCartney 2014

Chapter 1: General Introduction

Hunting has significant social and economic implications throughout the world (Sharp & Wollscheid, 2009); its purposes can be utilitarian, philosophical, spiritual, cultural, and social in nature, with its development and continuation deeply bounded by tradition (Baldassarre & Bolen, 2006). Indeed, hunting has been an important part of the New Zealand culture for centuries (Fraser, 2000). Maori (*ca.* AD 1300) have a long history of hunting birds in New Zealand for food (Duncan et al., 2002). English settlers (AD 1769) brought with them their own hunting culture of shooting for sport rather than as a necessity for obtaining food (Dunlap, 1999). Today, hunting in New Zealand revolves around a suite of introduced game species and the average hunter tends to be motivated by the outdoor experience combined with the opportunity to procure food. While the availability of trophy animals and sport shooting might be less of a motivator, the red deer *(Cervus elaphus scoticus)* rutting season and opening of the waterfowl season traditionally remain significant events in recreational hunters diaries, reflecting the social aspect shared in the activity (Fraser, 2000).

A 1988 survey estimated national totals for recreational hunting effort consumed 4.4 million hunter days, a gross expenditure of $100 million NZD, and the overall harvest of 6.5 million animals (Nugent, 1992). Approximately 3.5% of the New Zealand population identified themselves as hunters, with small-game hunting being most popular (81%), followed by gamebird (48%) and big game hunting (42%) (Nugent, 1992). A more recent survey in 1991 found that 7% of male New Zealanders rated hunting as one of their favourite leisure activities, with a higher representation in rural (14%) compared to urban (3%) males (Cushman et al., 1991). However, overall recruitment of hunters has declined over time. An erosion of interest or access to hunting, perhaps due to increased urbanization, are potentially detrimental to the conservation of both wild game animals and their habitats due to lost revenue and support for management. While New Zealand game species were introduced and are recognized as both a resource (commercially and recreationally) and a pest (Fraser, 2000; Nugent, 1992), management of game species provides motivation for conserving wild spaces and rare habitats in New Zealand.

1.1 Mallards in New Zealand

Combined mallard *(Anas platyrhynchos)* and native grey duck *(A. superciliosa)* harvest dominate gamebird activities in New Zealand. Similar appearance and extensive hybridization have resulted in these species being combined for game management purposes and hereafter I refer to mallards, but recognize some unknown proportion of that population comprises grey ducks and grey duck-mallard hybrids (Rhymer et al., 1994). Schedule 1 of the Wildlife Act (1953) declares the mallard duck to be a game species, and consequently to be managed by the New Zealand Fish and Game Council. Harvest of mallards is managed relatively independently by 12 regional Fish and Game Councils, which set bag limits and method restrictions, and regulate season lengths according to population counts and harvest trends. While hunting is a relatively expensive form of recreation (Baldassarre & Bolen, 2006), New Zealand hunters value mallards as a gamebird, spending more per bird harvested than any monetary worth that could be gained from the birds commercially (Nugent, 1992). In 2014, over 33,000 gamebird licenses were sold, representing approximately $3 million in revenue to New Zealand Fish and Game (NZ Fish and Game Council, unpub. data).

Mallards were first imported to New Zealand with enthusiastic determination so newly-arrived British settlers could be surrounded by familiar fauna (McDowall, 1994). The first imports were from English game farm stock in 1867 (Williams, 1981). Despite widespread releases, the early introduction was not particularly successful until closer to the 1930s, with those importations originating from a game farm in Connecticut, USA. Over 30,000 mallards were subsequently bred and released throughout New Zealand by Acclimatization Societies (Dyer & Williams, 2010), but unfortunately exact release sites were not recorded (Balham, 1952). Mallards are relatively tolerant of human disturbance with numbers flourishing through the 1970s while land development and intensification of agriculture changed the landscape (Caithness, 1982).

Mallards are dependent upon wetlands, lakes, and rivers for feeding, moulting, and brood-rearing, and areas of natural grass for nesting (Baldassarre & Bolen, 2006; Batt et al., 1992). Mallards have a ubiquitous distribution throughout New Zealand, but tend to be most abundant in locations where they exploit feeding opportunities in crops and livestock feed around pastoral landscapes and urban areas, with movement and dispersal focused on water bodies in proximity to anthropogenic disturbances (Balham, 1952; Williams & Basse, 2006). However, over the last decade, the hunting community has become increasingly concerned at the apparent decline of the species, particularly noted in much of the North Island where harvest per hunter has declined significantly. Further research is needed to determine whether this represents a real decline in mallard abundance.

Apart from indirect information gathered on mallards in New Zealand through studies often focused on the New Zealand grey duck, knowledge of mallard habitat use, breeding ecology, and reproductive success specific to New Zealand is inadequate. Extrapolations from North American mallard studies, while somewhat informative, are likely to be inaccurate due to differences in environment, migratory, and reproductive behaviours between birds in these populations (Rhymer, 1992), as well as due to differences in habitat availability and use (Baldassarre & Bolen, 2006). Knowledge of recruitment (i.e.: the number of female offspring produced per breeding female) and cause-specific mortality events (both hunting and non-hunting related) are of seminal importance in understanding trends affecting mallard populations, and to enable managers to develop effective harvest strategies (Sargeant & Raveling, 1992).

Numerous human-induced changes in the environment have altered various components of waterfowl productivity, including decreased availabilities of wetland and rank grass that in North America are known to reduce nest success and brood survival (Baldassarre & Bolen, 2006; Kadlec & Smith, 1992; MacLeod & Moller, 2006). Conversion of land use from sheep and deer operations to dairying has led to changes in vegetation height, density, and the degree of human disturbance during critical phases of the breeding season (Z. Moss, NZ Fish & Game, pers. comm.).

In response to concern at the apparent reduced abundance of mallards, a national study was devised by New Zealand Fish and Game with four main objectives:

i) To determine the incidence of non-breeding hens;

ii) To assess survival of nests and broods and identify causes of nest and duckling mortality;

iii) To determine the patterns of habitat use during specific life-history phases; specifically during nesting, brood-rearing, and moult;

iv) To develop a population model to identify influential vital rates and habitats affecting population change.

This thesis is a single component of the larger national project addressing objectives ii and iii, focusing on duckling survival and the related fitness consequences of habitat selection over the brood-rearing period.

Mallard productivity is dictated by two distinct events: firstly the successful hatching of a clutch, and secondly, the raising of hatched ducklings to fledgling stage. Nest success (i.e., the probability that at least one egg hatches from a clutch) is recognized as the vital parameter governing mallard recruitment in North America (Greenwood et al., 1995; Hoekman et al., 2002; Johnson et al., 1992; Walker et al., 2013b), with duckling survival being the next key component (Amundson & Arnold, 2011; Howerter et al., 2014). Both these vital rates are influenced by habitat selection of females.

Supported hypotheses concerning waterfowl habitat selection are based on food availability at the landscape scale, but additionally on predator avoidance at finer scales (Eichholz & Elmberg, 2014). Considering nest predation is a major cause of nest failure in waterfowl species, the safe placement of a nest site is an important factor for female mallards (Sargeant & Raveling, 1992; Walker et al., 2013b). In North America, nests are typically more successful when located in landscapes with a higher percentage of grass vegetation (Horn et al., 2005), and with fewer wetlands (Mack & Clark, 2006; Thompson et al., 2012). Nest predation increases with increasing human housing density (Thorington & Bowman, 2003). Nesting females tend to select taller and thicker vegetation, with the height of cover being most important in landscapes with predominantly avian predators, and cover density being most important where mammalian predators are most common (Eichholz & Elmberg, 2014). However, a trade-off exists between nest concealment and the ease of escape from predators by the female (McRoberts et al., 2012).

A female might improve nest success by selecting a nest site away from wetlands where predators are less abundant. However, a trade-off exists because duckling survival is maximised when the nest is located close to a wetland (Ball et al., 1975; Poysa et al., 1999). In North America, duckling survival is highest when the surrounding landscape contains numerous wetlands, but is negatively correlated with increasing areas of managed hayland (Bloom et al., 2012). Ducklings require a high protein food source for adequate growth and development (Cox Jr. et al., 1998; Street, 1978), and aquatic invertebrate availability (a primary food source for ducklings) is typically higher in semi-permanent or temporary water bodies than permanent sources (Krapu et al., 1997; Krapu et al., 2006; Talent et al., 1982). At times, duckling survival can limit population growth and is an important driver for waterfowl populations (Amundson et al., 2013; Howerter et al., 2014)

In New Zealand, the majority of mallard habitat is confined to privately owned farmland, where growing pasture is the main objective for feeding livestock. Depending on the livestock system, management of pasture varies. Sheep and deer systems tend to be ‘set-stocked’ with animals distributed at low stocking rates across all pastures for lambing and fawning, which coincides with the mallard-breeding period. This results in pastures with continually grazed short grass, high animal disturbance, but minimal anthropogenic disturbance. In contrast, the majority of dairy pastures are left ungrazed until the completion of calving (late winter/early spring), when pastures are typically rotationally grazed with brief periods of having animals distributed at high stocking rates on a single pasture causing high anthropogenic and animal disturbance over that short period. In some cases with feed surpluses, pastures can be left to reach ceiling yields when they will be cut for silage, usually later in the spring. As a result, grass height is much more variable and taller in dairy pastures during the mallard brood-rearing season, and this might result in differences in habitat use, brood survival, and predation rates in these areas.

Rotational grazing is a method used to increase grass production by allowing pastures a period to recover between brief periods of intense defoliation (Hormay & Talbot, 1961). In North America, waterfowl productivity has been shown to increase in years when cattle pastures were recovering, and decrease in years when grazed, with an overall positive response in productivity noted when pastures were rotationally grazed in comparison to season-long grazing (Gjersing, 1975; Holechek et al., 1982; Mundinger, 1976). However, in New Zealand the productive nature of the climate and landscape means pasture growth is much more rapid, and pastures are rotationally grazed at the much higher frequency of several weeks, as opposed to months or years.

The focus of this study is to explore the survival consequences of habitat selection made by brood-rearing females in sheep and deer, or dairy pasture management systems and evaluate other factors that may influence duckling survival. This will inform future habitat management decisions, and contribute to the ultimate goals of the NZ Fish & Game productivity study.

1.2 Thesis Objectives and Structure

The overarching objective of this study is to increase understanding of how habitat components affect mallard productivity in New Zealand. This thesis is set out as two core, self-contained chapters, addressing duckling survival (Chapter 2) and habitat selection (Chapter 3), sandwiched between a General Introduction (Chapter 1) and General Discussion (Chapter 4). Specific objectives are set out in the following data chapter descriptions.

Chapter 2: Duckling Survival

I quantified factors affecting duckling survival, considering individual, temporal, environmental, and habitat variables associated with the brood-rearing period. In North America, duckling survival is lowest during the first week of life (Baldassarre & Bolen, 2006; Bloom et al., 2012; Gendron & Clark, 2002), and further compounded by environmental stressors such as temperature and precipitation (Amundson & Arnold, 2011; Bloom et al., 2012; Krapu et al., 2006; Pietz et al., 2003). Young ducklings have lower nutrient reserves (i.e., fat) and are unable to fully thermoregulate, and consequently are more susceptible to adverse weather and food conditions than older ducklings (Baldassarre & Bolen, 2006; Sedinger, 1992). Rotella & Ratti (1992) and Bloom et al. (2013) found ducklings that travelled further from the nest site had lower survival rates than those who travelled less, hence, during this time period, long grass may impede travel and the ability of individual ducklings to keep up with broodmates. Conversely, long grass may lower detection rates for certain predators, especially avian species such as the swamp harrier *(Circus approximans)* or pukeko *(Porphyrio melanotus).* Specifically, this chapter considers:

(i) Does land use and pasture management affect duckling survival?

(ii) What other intrinsic and extrinsic factors influence duckling survival?

I hypothesize that young ducklings will have low survival rates if they experience poor weather conditions early in life, or are reared on dairy pastures that achieve tall pasture covers with high herbage mass.

Chapter 3: Habitat Selection

Current and future fitness of an individual can be significantly affected by choices made during the reproductive period (Howerter et al., 2008). Selection of nest and brood-rearing sites by female mallards is an important individual choice with implications for population management (Arnold et al., 2012; Gloutney & Clark, 1997; Greenwood et al., 1995; Hoekman et al., 2002). Females should favour safe nest and brood-rearing sites with adequate food resources (Howerter et al., 2008). Many studies discuss habitat selection patterns, but few take this a step further and determine not only the fitness consequences of the habitat choice, but possible mechanisms underlying variation in survival (Jones, 2001; Michel et al., 2010). The characteristics of chosen resources could impact brood survival (Mauser et al., 1994), and affect waterfowl populations (Walker et al., 2013a). I quantified habitat selection by brood-rearing female mallards, and related this to duckling survival. The specific questions addressed are

(i) Do females select specific brood-rearing habitat?

(ii) Could habitat selection be adaptive from a life history perspective?

I hypothesize that female mallards that successfully reared broods will have selected habitat that is within or close to permanent water and/or dense nesting cover with high availability of food and protective cover from predators.

A marked mallard female and her brood cross a road with oncoming traffic in the study area, Southland, New Zealand, 2014.

Photo courtesy of Phil McCartney 2014

Chapter 2: Duckling Survival

2.1 Introduction

The New Zealand grey duck *(Anas superciliosa)* and the introduced mallard *(A. platyrhynchos)* typically rely on wetlands, lakes, and rivers for feeding, moulting, and brood-rearing, and areas of natural grass for nesting (Baldassarre & Bolen, 2006; Batt et al., 1992). Dramatic wetland drainage and landscape change for agricultural development in New Zealand (NZ) (MacLeod & Moller, 2006) are postulated to have led to the perceived decline in their combined populations in certain regions. Mallards and grey ducks comprise the majority of a gamebird hunter’s bag (Barker, 2006), representing 73% of harvest across the country (Nugent, 1992). Thus, these waterfowl are important to sportsmen, and help provide an incentive for the establishment and conservation of habitat that benefits numerous species. In recent years, hunters have been expressing concern regarding perceived population declines, and in Southland, have suggested the cause might be due to a decrease in duckling survival due to the continual conversion of short-grass sheep and deer pastures to long-grass dairy pastures (Z. Moss, NZ Fish & Game, pers. comm.). Some hunters postulate that the long, dense cover in pre-grazing dairy pastures might be more energetically expensive for ducklings to traverse, especially early in life (Amundson & Arnold, 2010), resulting in increased separation and consequent brood loss.

Female mallards are very similar in appearance to the grey duck, and hybridization has led to the combined management of the species. Therefore, herein I refer to mallards, but realize there is an unknown proportion of the mallard population that includes grey ducks, and grey-mallard hybrids (Rhymer et al., 1994).

Duckling survival, along with nesting success (i.e., the probability that at least one egg hatches from a nest) and adult female survival, are known to be key drivers of changes in waterfowl populations (Amundson et al., 2013; Chouinard & Arnold, 2007; Hoekman et al., 2002; Howerter et al., 2014). However, due to the mobile and cryptic nature of females with ducklings, much less is known about brood ecology than nesting ecology (Sargeant & Raveling, 1992; Sedinger, 1992; Walker et al., 2013a). Despite the challenges of studying brood ecology, weather, habitat conditions, season date, and female characteristics have been shown to influence duckling survival in a myriad of ways. Habitat composition, especially the availability of shallow wetlands, is critical for ducklings, particularly early in life. Mallard broods are highly mobile immediately post-hatch (Sargeant & Raveling, 1992; Sedinger, 1992), and ducklings that hatch in areas with low water availability must travel further, and consequently have lower survival than those that have water available nearby (Rotella & Ratti, 1992). Most duckling loss occurs in the initial movement from nest site to water, regardless of distance (Mauser et al., 1994), or in the first movement overland between wetlands

(Yerkes, 2000). Nevertheless, duckling survival is negatively correlated with distance covered in overland movement, particularly travel in the first two weeks of life (Ball et al., 1975).

Habitat composition also influences predator presence, density, and hunting behaviour (Bloom et al., 2012). Krapu et al. (2000) found total brood loss in North Dakota was > 11 times more likely to occur for broods hatched in areas where there were fewer total inundated seasonal wetland basins (i.e., those that are often dried by the end of the breeding season) compared to areas with an abundance of seasonal basins. Mink *(Neovison vison)*, a main duckling predator in those ecosystems, are positively associated with permanent water sources (i.e., those that retain water year-round), and subsequently higher duckling brood survival was attributed to areas where seasonal wetlands dominated the landscape (Krapu et al., 2000; Krapu et al., 2004). Habitat composition can change rapidly throughout the breeding season (Mack & Clark, 2006), and seasonally high precipitation often forms ephemeral wetlands (i.e., temporary bodies of water in soil depressions that contain plentiful aquatic invertebrates (Sedinger, 1992)), creating popular feeding grounds for mallards. Accordingly, the presence of ephemeral water might mean ducklings do not need to be as mobile, thus improving their survival (Ball et al., 1975).

Land use can also affect duckling movement and predation rates. Livestock pasture is the dominant land use in NZ and notable seasonal habitat differences exist among pastoral management systems. Sheep and deer tend to be ‘set-stocked’ with animals distributed at low stocking rates across all pastures for lambing and fawning, which coincides with the mallard nesting and hatching period. This results in pastures with continually grazed short grass and frequent animal disturbance, but minimal anthropogenic disturbance. In contrast, the majority of dairy pastures are left ungrazed until the completion of calving (late winter/early spring). Pastures are then rotationally grazed with brief periods of animals distributed at high stocking rates causing high anthropogenic and animal disturbance over a short period. In some cases, dairy pastures are left to reach ceiling yields when they will be cut for silage, usually later in the spring. As a result, grass height is much taller and denser in dairy pastures during the mallard brood-rearing season and differs from deer and sheep systems in the amount of disturbance, which might result in differential habitat use and brood survival in these areas.

In North America, duckling growth (Cox Jr. et al., 1998) and survival decrease when minimum air temperature is < 10 degrees Celsius during the brood-rearing period (Howerter et al., 2014). This effect is most pronounced early in life (Amundson & Arnold, 2011; Bloom et al., 2012; Krapu et al., 2006; Pietz et al., 2003) as ducklings are unable to thermoregulate fully, and consequently are highly susceptible to adverse weather, particularly if there are also poor food conditions (Baldassarre & Bolen, 2006; Sedinger, 1992). Duckling survival is negatively correlated with increased precipitation (Bloom et al., 2012; Krapu et al., 2000), but this can be offset by increased presence of ephemeral water bodies (Krapu & Reinecke, 1992). Ducklings require sufficient protein for adequate growth and development and ephemeral water bodies create shallow habitat for aquatic invertebrates, a primary duckling food source (Street, 1978). Further, ephemeral water saturates the soil, forcing earthworms to the surface where they are foraged upon by ducklings (Cox Jr. et al., 1998; Sedinger, 1992; Swanson et al., 1985).

Female choice surrounding nesting can be influenced by factors such as available habitat cover, presence of ephemeral water, temperature, precipitation, and both predator and alternative prey abundance. Date of hatch can affect brood survival in North America, with an earlier hatch date positively correlated with survival (Afton & Paulus, 1992; Amundson & Arnold, 2011; Dawson & Clark, 2000; Dzus & Clark, 1998; Krapu et al., 2000). Ducklings hatched earlier in the season could be better able to maximise nutrient acquisition before realizing migration expenditure (Dawson & Clark, 2000), or increased wetland availability earlier in the season might increase food availability (Dzus & Clark, 1998). In contrast, the NZ mallard population has a prolonged nesting period (range: June – January) and lacks the seasonal selection pressure that forces their North American counterparts to migrate. Nevertheless, temperature increases and precipitation decreases throughout the breeding period leading to seasonal variation in wetland availability (Balham, 1952).

Female and Brood Attributes

Older females typically invest more in reproductive effort, are more successful and have greater nest, brood and individual survival than younger females (Devries et al., 2008; Devries et al., 2003; Kaminski et al., 2013). Larger clutches are typical of older females that both nest earlier in good body condition (Devries et al., 2008; Krapu, 1981). Younger females might have smaller clutches as a result of smaller size and lower body condition compared to older females (Rotella et al., 2003) and might provide poorer parental care due to inexperience and/or lower maternal investment. For these females, brood size will negatively influence mothering efficacy and duckling survival (Afton & Paulus, 1992; Dzus & Clark, 1997a; Johnson et al., 1992).

Most of the knowledge of duckling ecology comes from studies of radio-marked brooding females in temperate North America, which might not be relevant to mallard ducklings in NZ. Previous research suggests duckling survival and factors affecting survival vary substantially in location and time, likely as a result of fluctuating environmental conditions and habitat availability (Baldassarre & Bolen, 2006). To date, no published studies report estimates of mallard duckling survival or factors affecting survival in NZ. Thus, in 2014, I marked breeding female mallards with radio transmitters and followed broods in Southland, NZ with the aim of a) estimating mallard duckling survival to 30 days of age, and b) evaluating the impacts of habitat, climate, and brooding female characteristics on duckling survival. I hypothesized that young ducklings would have relatively low survival rates if they experience poor weather conditions early in life, or are reared on dairy pastures containing tall, dense cover. This might be due to overland movement through this habitat being more energetically expensive and resulting in ducklings becoming more easily separated from their dam and broodmates. Results from this study will inform mallard management and provide estimates that can be used to build a comprehensive population model for NZ mallards.

2.2 Methods

Study Site

The study was conducted on a 30 km^2 site centered on the Lochiel community (46°12´18.68´´S, 168°19´46.19´´E) just south of Winton, Southland in the South Island of NZ (Figure 2.1). The boundaries of the study site were defined by the outermost locations of marked females taken throughout the study period. Just over 15% of nation-wide gamebird licenses are purchased in the Southland region, known as a hotspot for mallards, although no population estimates exist (NZ Fish & Game Council, unpub. data). The region is typical of those across the country, having intensive agricultural production, mostly livestock, within a mosaic of highly fragmented habitats. The region encompasses a range of landscapes characterized by coastlines, mountain ranges, foothills and the Southland plains (Cochrane, 1960; Critchfield, 1954). Within this region, the study site was limited to the more homogenous plains country where agriculture dominates the landscape, specifically dairy, sheep, and deer management systems bifurcated by rivers and associated river flats. The study area was exclusively private land with numerous small man-made ponds created to either hold livestock waste (effluent ponds) or as waterfowl habitat. It is thought that the majority of Southland's mallards are produced across these plains (M. Rodway, NZ Fish & Game, pers. comm.).

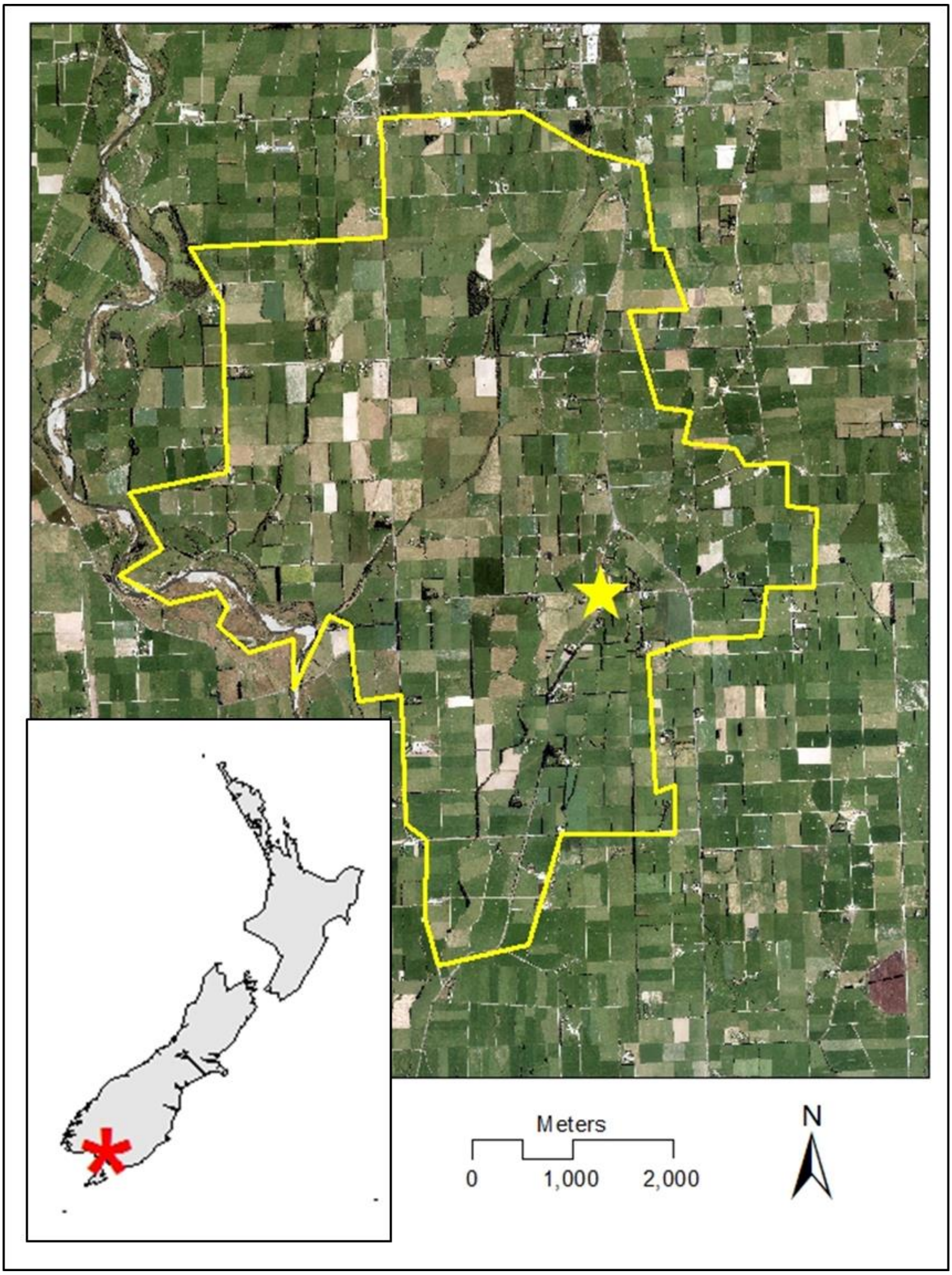

Figure 2.1: Map of New Zealand with a red star denoting the study site within the country (inset) and an aerial image of the general study area with the yellow star representing the Lochiel, Southland community. The yellow line signifies the outermost locations that marked female mallards used during the study. Aerial images courtesy of Environment Southland, captured 5 February 2014.

Capture and Marking

From 1 July 2014, I captured female mallards from three locations using walk-in baited funnel traps (Cleary, 1994). Sites used for female capture within this region were selected from aerial images on the basis of representative habitat for the area, landowner permission, and where no hunting was undertaken in the weeks leading up to capture. Thus, females captured were assumed to be representative of the local population. Upon capture, a NZ Department of Conservation metal leg band with a unique number was attached to the left leg of all females. Age was determined as second-year (SY) or after-second-year (ASY) primarily by bursa depth (Hanson, 1949), and then by inspecting the greater secondary coverts (Krapu et al., 1979), and four distal primary coverts (Carney & Geis, 1960; Hopper & Funk, 1970; Pearse et al., 2014). Morphological measurements were collected as an index for body condition with digital calipers (+/- 0.1mm) including tarsus length (tarsometatarsal bone), keel length, head-bill length (back of head to beak tip) and culmen; flattened wing chord was measured with a ruler (+/- 1 mm) from the carpo-metacarpus to the tip of the longest primary feather. Birds were weighed with a Pesola scale (+/- 10 g). For possible future studies by project partners, flank feathers were pulled for isotope or corticosterone analysis (Bortolotti et al., 2008) and approximately 1.5 mL of blood was collected (via jugular) for genetic analysis, heavy metal contaminants, and/or blood parasite testing.

Females were then anesthetized using isoflurane (average 6.3 mL per female) in a surgery unit and implanted with a 22 g intra-abdominal radio-transmitter (Model IMP/150, Telonics, Mesa, Arizona, USA; modified from (Olsen et al., 1992)) in the abdominal cavity lateral to the liver. This transmitter type has been shown to have negligible effects on reproductive effort in comparison to other options such as external antenna implants (Paquette et al., 1997; Rotella et al., 1993). Pre-operative handling and surgery time averaged 16 and 22 minutes, respectively. After surgery and upon waking, females were placed in a crate for 45 minutes to recover and were then released near their capture site. In accordance with the Animal Welfare Act 1999, all procedures used in this study were approved by the University of Auckland Animal Ethics Committee (Protocol # 001331) and cleared by the University of Otago under this permit.

Brood Observations

Radio-marked females were located by triangulation every 2–5 days using vehicle-mounted, null-peak antenna systems (Gilsdorf et al., 2008). Once a female was consecutively triangulated to the same location three times, she was approached by homing in on her radio signal to determine nesting status. If confirmed to be nesting, eggs were candled to determine incubation status (Weller, 1956), with the start of incubation signaling the completion of a clutch. Egg measurements (length and width) were recorded with Vernier calipers to the nearest 0.1 mm, and the nest revisited every 7–10 days until I determined nest fate (failed or hatched). If the nest failed, the female was monitored weekly until any renesting attempt was initiated, at which time monitoring resumed as above. If the nest hatched successfully, the brood was located via homing telemetry every day for the first 10 days post-hatch, with visual contact made every three days if possible, and thereafter every five days until the female could no longer be found, or until ducklings reached approximately 30 days of age. Once a female was seen without ducklings over two consecutive resightings, I assumed total brood failure and she was monitored weekly to check for renesting.

Nesting habitat was systematically searched within the study area to locate additional nests to obtain a larger sample size of nesting females. Once found, eggs were candled to estimate hatch date and females were trapped on the nest no earlier than 20 days into incubation (Rotella & Ratti, 1990) using a mist net (Bacon & Evrard, 1990), an automatic nest trap (Blums et al., 1983; Weller, 1957) or a walk-in trap (Dietz et al., 1994). Captured females were fitted with a back-mounted, 10 g prong-and-suture radio transmitter (Telonics, Mesa, Arizona, USA; (Pietz et al., 1995) modified from (Mauser & Jarvis, 1991)). Handling and surgery time averaged 31 minutes, with females given a local anaesthetic and released immediately after transmitter attachment. Radio tracking and monitoring of nest-marked females were carried out in the same manner as for the intra-abdominal radio-transmittered females.

Habitat Classification

I used ArcGIS (*v.* 10.2; ESRI Inc., Redlands, CA, USA) to create a digitised land-cover layer from colour aerial photographs (cell size of 0.4 m, resolution 1:1500) taken 5 February 2014 by New Zealand Aerial Mapping Ltd (NZAM). This level of recent detail allowed habitats to be easily delineated into five categories: permanent water (ponds, streams and ditches), anthropogenic features (houses and roads), dairy pastures, sheep and deer pastures and dense nesting cover (rank grass, road edges, woodlots, shelterbelts). I confirmed digitised habitat maps via ground-truthing to verify layer accuracy. I used the *Near* tool in ArcGIS to generate distances to closest habitat features for all brood locations. For brood movement, I used the *Split at Vertices* tool in ArcGIS to estimate distances travelled between locations assuming a straight line trajectory. Distances were averaged across observations from nest site to the last known-alive location, or until the brood reached 30 days of age.

Brood Data

A Julian-like date began when the first nest hatched on 11 September 2014. Brood size was measured as the number of ducklings that successfully left the nest bowl. Egg size was determined as an average length *(l)* and breadth *(b)* per nest, with corresponding egg volume calculated with the formula

$$\mathbf{Volume = K_v lb^2}$$

with $K_v = 0.515$, a constant specific for *Anas platyrhynchos* (Hoyt, 1979).

I downloaded minimum air temperature and precipitation from the National Climate Database (*cliflo.niwa.co.nz*) using data collected from the weather station 600 m north and in closest proximity to the study site (“Winton2,” Agent #:5768). I weighted both precipitation and minimum temperatures over the first ten days post-hatch using a linear decay where day one was most important to duckling survival to account for the adverse weather during the early post-hatch period (see Amundson and Arnold 2011).

I digitised brood locations in ArcGIS v. 10.2 from field maps created over the season. Field technicians marked on a detailed map where the brood was counted (if seen), or hidden (if homing techniques led them to a distinct location). A successful brood was confirmed by the observation of one or more ducklings surviving to 30 days post-hatch. I had hoped to observe ducklings until fledge (day 52–60 in North America (Afton & Paulus, 1992; Baldassarre & Bolen, 2006; Rhymer, 1992)), and while many of the females were actively tracked until ducklings reached at least 45 days old, I chose 30 days as a cut off measure for three reasons. First, counts became more difficult past this point due to females taking brood breaks and because of frequent creching behaviour/brood amalgamations (Afton & Paulus, 1992; Eadie et al., 1988;

Johnson et al., 1992). Second, previous waterfowl studies suggest little change in survival between 30 and 45 days (Orthmeyer & Ball, 1990; Rotella & Ratti, 1992). Third, this allows for a comparable measure of data with other duckling survival studies that typically assess survival to 30 days post-hatch (Amundson & Arnold, 2011; Baldassarre & Bolen, 2006; Bloom et al., 2013; Pearse & Ratti, 2004).

Each duckling count was defined as being either full (ducklings were highly visible and believed to be accurately counted by the observer), suspected partial (incomplete duckling count only) and/or mixed (ducklings of various ages exhibiting creching behaviour), or unknown based on the degree of certainty of the observer. I omitted all mixed or unknown observations because a definitive count could not be made. Full counts were assumed to be most reliable, with partial counts providing additional data. If counts fluctuated, I erred on the conservative side, relying on full counts and later observations when brood detectability increased.

I measured habitat variables to the last known-alive location for ducklings within a brood that went missing during the same interval, as it was unknown exactly when (and where) death occurred. For ducklings that left the nest bowl, but which were not observed for any post-hatch count, habitat variables were taken from the nest site. I determined the number of ducklings that left the nest bowl by visiting the nest <24 hours after hatch, and counting unhatched eggs (Klett et al., 1986). If the female died before the brood reached 30 days of age, I censored the brood from the time of female mortality (i.e., when ducklings were last observed with the female). It is unknown if brood loss occurred simultaneously, as ducklings are unlikely to survive without a brooding female, especially when young. However, similar studies of individually webtagged ducklings have subsequently discovered individuals alive at later dates after the female had been killed (Gendron & Clark, 2002).

Brood Routes

I created brood routes in ArcGIS using the *Point to Line* feature, assuming straight line movement from the nest site to first female location and to subsequent known, consecutive locations until the female was last observed with ducklings, or became ‘successful’ at 30 days post-hatch. I created a 50 m radius buffer to assess categorised habitat on either side of the segmented straight line movements using the *Buffer* and *Clip* tools in ArcGIS. A 50 m radius buffer (100 m across) was approximately equal to the average distance moved per day. I made brood movement an artificial straight-line trajectory as the actual route taken was unknown but assumed to fluctuate around this line, but presumably within the buffer.

Statistical Analysis

I considered a set of variables including environmental, temporal, and female characteristics that have been supported previously in other waterfowl survival studies or apply directly to habitat management in NZ. Specifically, the set of variables included a log-linear trend for duckling age (LogAge), and effects of female age (Fage; SY or ASY), length of pasture where the brood spent the majority of their first ten days of life (Pasture; long or short), the presence or absence of ephemeral water within 100 m of the brood route (Ephemeral), within-season hatch date (Date), brood size (Bsize), egg size (Esize), 10-day average weighted precipitation (Precip), average distance to anthropogenic sources (Dhouse), average distance to permanent water body (Dwater), percentage of dense nesting cover within brood routes (PercNat), and average distance moved between consecutive brood locations (Dmoved). I initially considered the effect of temperature weighted across the first 10 days of life on duckling survival, but this was strongly correlated with season date and preliminary analyses suggested season date had greater predictive power than temperature and thus, I did not include it in the final variable set. All continuous variables were centered and standardised to mean = 0 and SD = 1 to facilitate model convergence and comparison among effect sizes.

I was unable to identify the exact failure date for ducklings because broods were not monitored daily. Rather, I knew they had died during the interval between last being seen alive and observing the brood without one or more ducklings. Thus, these data are referred to as ‘ragged telemetry’ making analysis of known fates inappropriate (Dinsmore et al., 2002; Rotella et al., 2004). Instead, I completed analyses using the Nest Survival module of Program MARK, which uses the entire dataset to estimate the most likely time of death for ducklings during the interval in which they died (White, 2015). This approach also allows examination of fixed-effect covariates. I used Akaike’s Information Criterion adjusted for small sample size (AIC_c) to evaluate relative model fit (Burnham & Anderson, 2002). This approach identifies the strongest candidate model based on the lowest AIC_c value. Data may be overdispersed if fates of individual ducklings within a brood are not independent. For example, whole broods are exposed to similar maternal and environmental variables, and predation events. Therefore, I adjusted AIC_c to quasi-AIC_c ($QAIC_c$) using an overdispersion coefficient ($\hat{c}$) (Symonds & Moussalli, 2011). I calculated overdispersion ($\hat{c} = 4.5258$) by running 5,000 bootstrap simulations on the most parameterized model in my candidate set (Bishop et al., 2008). I derived 85% confidence intervals around model-averaged cumulative survival estimates using MCMC simulations as per Arnold, 2010.

While AIC is best used with a small set of *a priori* models (Burnham & Anderson, 2002), here the analysis was more exploratory. My covariate set was carefully selected to include biologically-plausible and management-related covariates that had been found to be important in other examinations of duckling survival, but I did not have hypotheses for which variables or combination of variables would be most supported, with one exception. Duckling age is known to influence survival, with survival rate typically increasing as ducklings get older (Amundson & Arnold, 2011; Krapu et al., 2006). Thus, I included a log-linear trend in duckling age (LogAge) in all models, and examined all possible subsets of the remaining covariate set (1024 models) where the global model was:

Duckling survival = Int + LogAge[β] + Fage + Ephemeral + Dhouse[β] + PercNat[β] + Dmoved[β] + Dwater[β] + Date[β] + Precip[β] + Pasture + Esize[β] + Bsize[β] + residual

I then calculated variable importance weights (i.e., the sum of the $QAIC_c$ weight for all models containing a particular covariate) to determine relative support for each covariate. I model-averaged cumulative survival estimates, but report only the coefficients for the most supported model that included variables with the greatest importance weight, because in multiple regression, coefficients vary in relation to other parameters in the model and are thus not directly comparable across models (Bishop et al., 2008).

2.3 Results

From 5 July to 22 September 2014, I implanted 62 females with abdominal transmitters and captured another 23 females on nests and attached prong-and-suture transmitters. Three abdominally implanted females died within three days, likely due to wet, cold and muddy conditions during marking. The remaining 82 females hatched 55 nests.

Five successful nests were censored from analyses due to various circumstances, including responses to investigator disturbance (n = 4), or transmitter failure upon nest exodus (n = 1). Therefore, 438 ducklings from 50 broods were included in the analyses. One female was killed by mowing machinery before her brood reached 30 days of age. Mean Esize was 56.80 cm^3 (range: 45.68–67.88) and mean Bsize was 9.06 ducklings (range: 5–15). I monitored broods from 11 September to 23 January 2015; hatch dates ranged from 11 September to 4 January 2015 (median: 26 September 2014). In total, 141 ducklings from 27 broods survived to 30 days post-hatch, and 20 broods experienced total brood loss. My sample included more after-second year (ASY) than second-year (SY) females (n_{ASY} = 29) and approximately half of broods were reared in predominantly dairy pastures (n_{long} = 26) and half had ephemeral water present ($n_{ephemeral}$ = 25). The habitat over the entire study area was categorized as 8.9% ‘dense nesting cover’ (including hedge rows, road verges, ditch edges, wetlands), 45.7% short sheep or deer farm pasture and the remaining 45.4% long dairy pastures, with varying degrees represented in the used-route buffer for each female (Appendix A, Table A2.3).

Duckling survival increased with duckling age (β = 0.05, 85% CI = 0.024–0.076, Figure 2.2), was greater when ephemeral water was present (β = 0.578, 85% CI = 0.148–1.009), and with greater average distance from brood locations to the nearest anthropogenic structure (β = 0.278, 85% CI = 0.017–0.539, Figure 2.3). Duckling survival was lower for SY females (β = -0.516, 85% CI = -0.901– -0.132), in areas with increased dense nesting cover (β = -0.375, 85% CI = -0.597– -0.153, Figure 2.4), and when ducklings moved, on average, greater distances (β = -0.33, 85% CI = -0.56– -0.099, Figure 2.5). Model-averaged cumulative duckling survival to 30 days of age ranged from 0.157 for SY females without ephemeral water present in short pasture to 0.423 for ASY females with ephemeral water present in long pasture (Table 2.1).

Several models received equivalent support (i.e., $\Delta QAIC_c < 2$), however, the best-supported model included all variables with variable importance weight > 0.5 (Table 2.2). For this model, mean cumulative duckling survival to 30 days of age for broods with ephemeral water present was 0.277 (85% CI = 0.217-0.342) for SY females and 0.462 (85% CI = 0.409-0.514) for ASY females; without ephemeral water present, duckling survival was 0.106 (85% CI = 0.069-0.15) and 0.256 (85% CI = 0.203-0.312) for SY and ASY females, respectively.

Table 2.1: Model-averaged estimates of cumulative duckling survival to 30 days post-hatch for mallard ducklings in eight attribute groups related to female age (Fage; SY = second-year, ASY = after-second-year), pasture type (Pasture; L = long grass, S = short grass), and whether ephemeral water was present during brood-rearing (Ephemeral; Y = yes, N = no) in Southland, New Zealand, 2014.

Fage	**Pasture**	**Ephemeral**	**Estimate**	**SE**	**85% LCI**	**85% UCI**
SY	S	Y	0.277	0.109	0.129	0.447
SY	S	N	0.157	0.089	0.05	0.302
SY	L	Y	0.296	0.117	0.134	0.475
SY	L	N	0.173	0.097	0.053	0.328
ASY	S	Y	0.404	0.099	0.267	0.550
ASY	S	N	0.267	0.101	0.132	0.423
ASY	L	Y	0.423	0.095	0.283	0.563
ASY	L	N	0.285	0.098	0.151	0.436

Table 2.2: Variable importance weight and its relationship to mallard duckling survival in Southland, New Zealand, 2014.

Parameter[a]	**Importance Weight**	**Association**
PercNat	0.81	-
Fage	0.68	- (SY)
Ephemeral	0.67	+ (when present)
Dmoved	0.65	-
Dhouse	0.52	+
Esize	0.39	+
Bsize	0.36	+
Date	0.33	-
Pasture	0.32	+ (long)
Dwater	0.31	-
Precip	0.28	-

[a] Parameters include: PercNat = percentage of dense nesting cover within brood routes, Fage = female age, Ephemeral = the presence or absence of ephemeral water within 100 m of the brood route, Dmoved = average distance moved between consecutive brood locations, Dhouse = average distance to anthropogenic sources, Esize = egg size, Bsize = brood size, Date = within-season date, Pasture = length of pasture where the brood spent the majority of their first ten days of life, Dwater = average distance to permanent water body and Precip = 10 day average weighted precipitation.

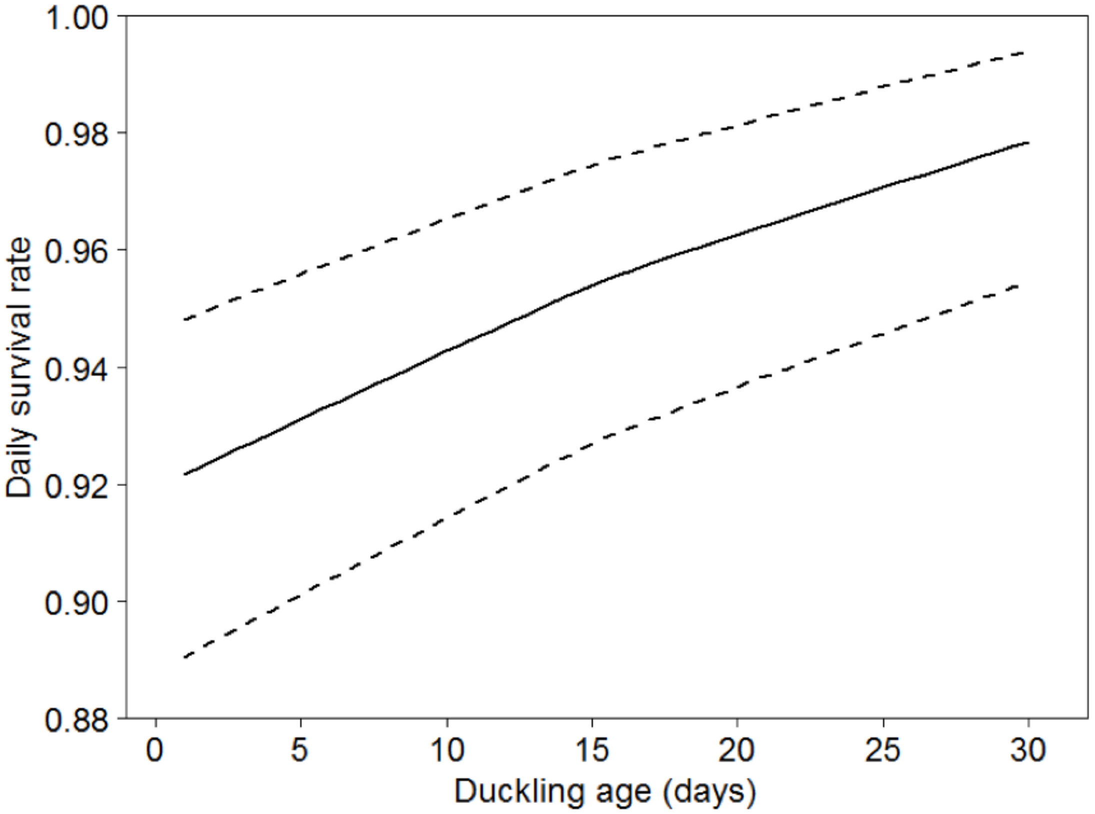

Figure 2.2: Model-based estimates of daily duckling survival with 85% confidence intervals (dashed lines) in relation to age (days) for mallard broods in Southland, New Zealand, 2014. Estimates are for after-second-year females without ephemeral water present with continuous covariates held at mean values (area of dense nesting cover per brood route = 13.2%, distance to anthropogenic sources = 234.5 m, distance moved = 118.4 m, initial brood size = 9.06 ducklings).

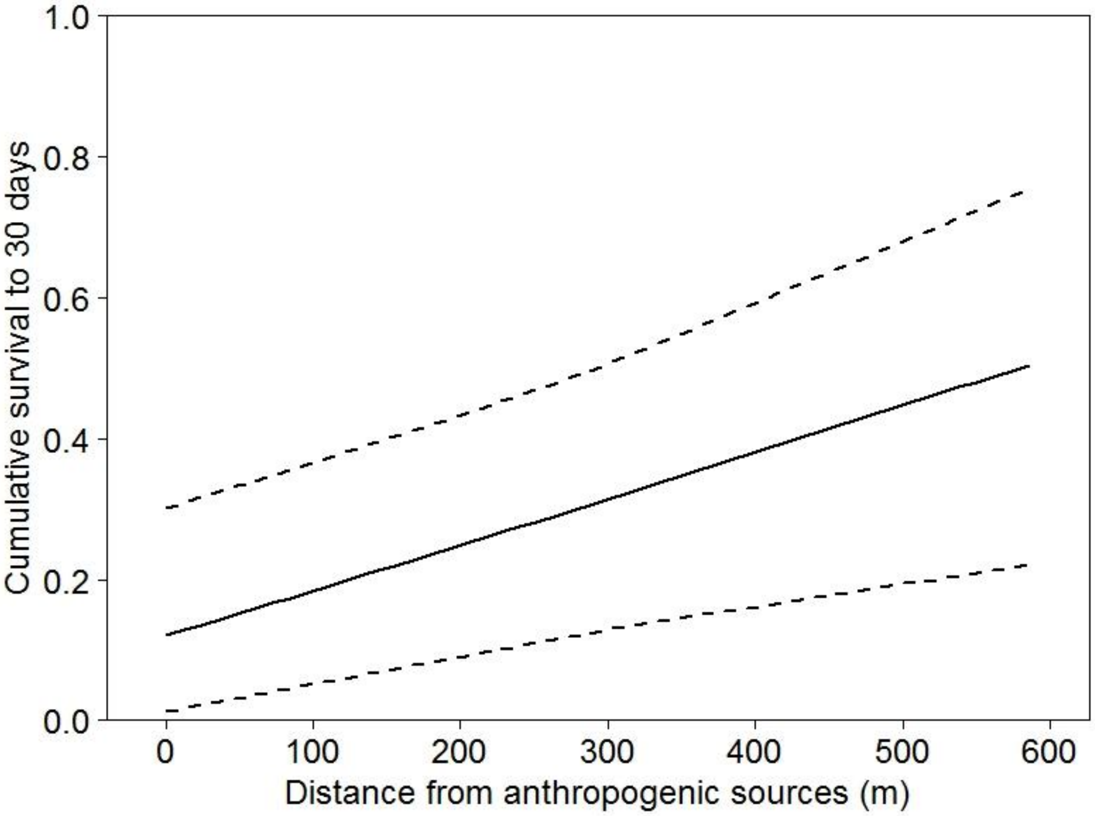

Figure 2.3: Model-based estimates of cumulative duckling survival to 30 days of age (solid line) with 85% confidence interval (dashed lines) in relation to the average distance from anthropogenic sources (e.g., houses, roads) of the brood route for mallard broods in Southland, New Zealand, 2014. Mean distance from anthropogenic sources was 234.5 m. Estimates are for after-second-year females without ephemeral water present with continuous covariates held at mean values (area of dense nesting cover per brood route = 13.2%, distance moved = 118.4 m, initial brood size = 9.06 ducklings).

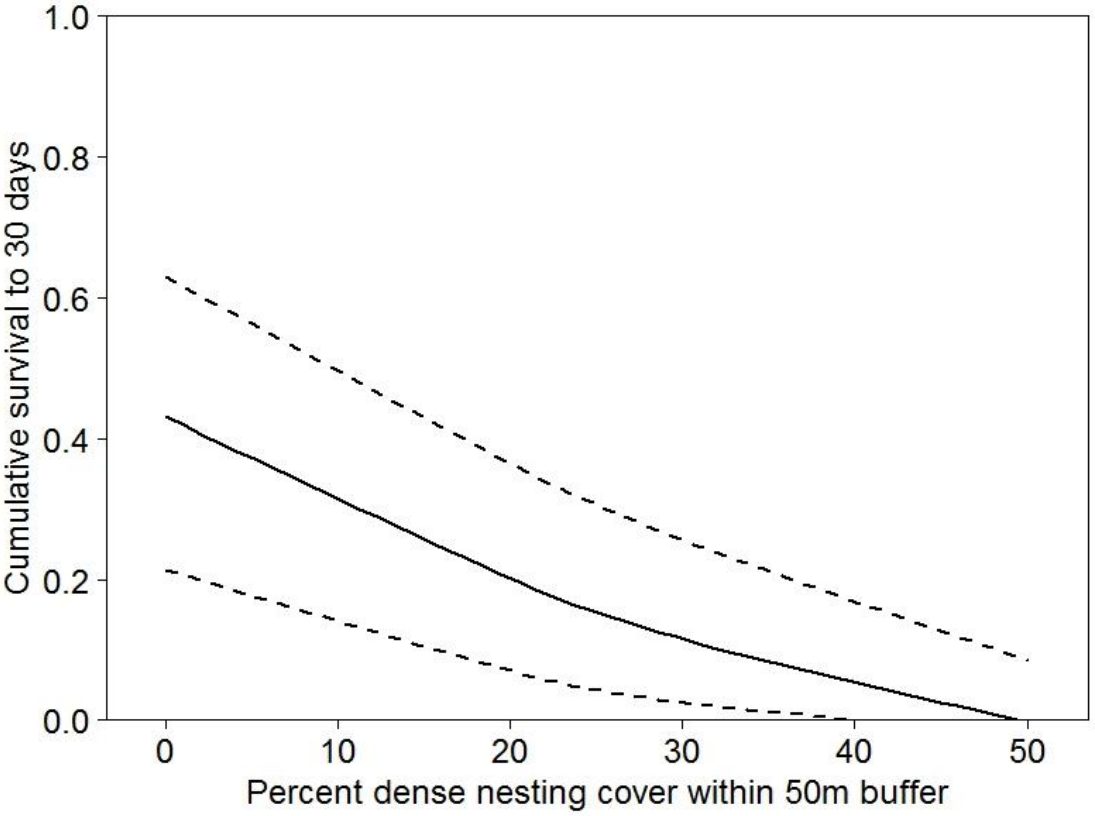

Figure 2.4: Model-based estimates of cumulative duckling survival to 30 days of age (solid line) with 85% confidence interval (dashed lines) in relation to the percent of dense nesting cover within the 50 m radius buffer for mallard broods in Southland, New Zealand, 2014. Mean area of dense nesting cover per brood route = 13.2%. Estimates are for after-second-year females without ephemeral water present with continuous covariates held at mean values (distance to anthropogenic sources = 234.5 m, distance moved = 118.4 m, initial brood size = 9.06 ducklings).

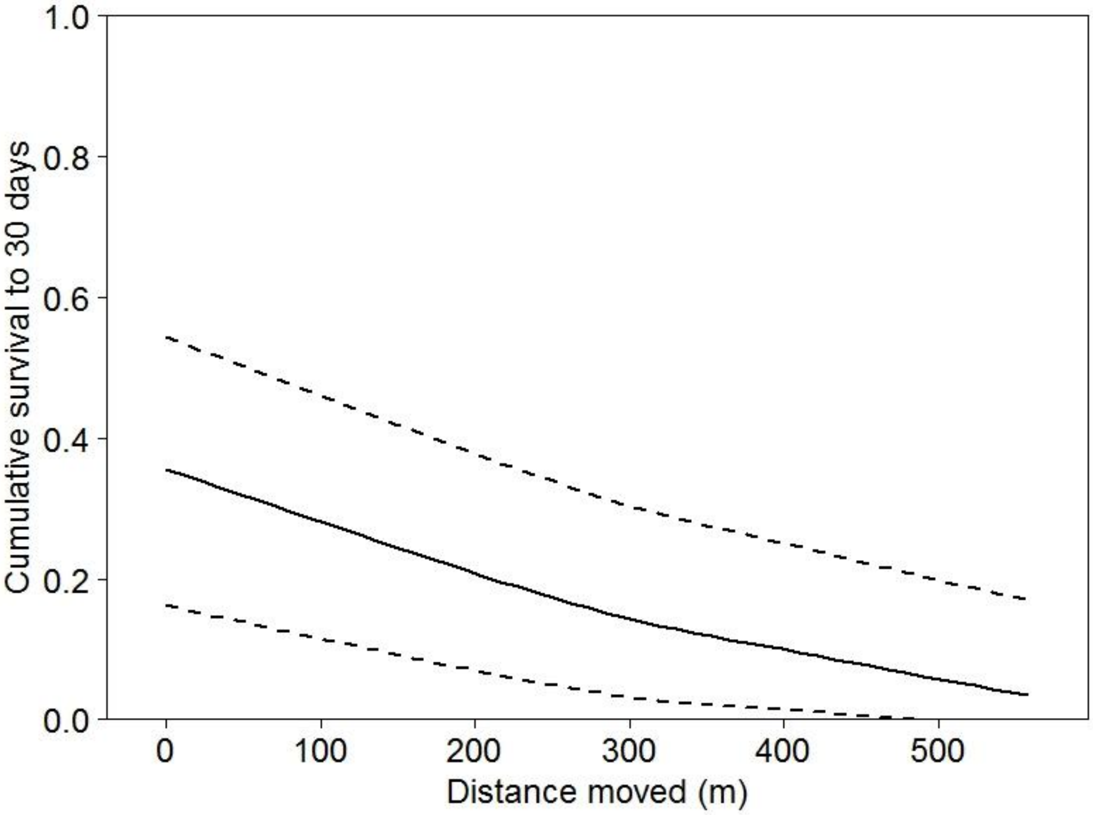

Figure 2.5: Model-based estimates of cumulative duckling survival to 30 days of age (solid line) with 85% confidence interval (dashed lines) in relation to average distance moved for the brood in 24 hours for mallard broods in Southland, New Zealand, 2014. Mean distance moved = 118.4 m. Estimates are for after-second-year females without ephemeral water present with continuous covariates held at mean values (area of dense nesting cover per brood route = 13.2%, distance to anthropogenic sources = 234.5 m, initial brood size = 9.06 ducklings).

2.4 Discussion

Contrary to game managers' concerns, overall pasture management did not appear to be a significant factor affecting duckling survival for mallard broods in Southland, NZ in 2014, and its small influence indicated duckling survival was marginally better in long rotational grazed rather than short set-stocked pastures. However, several factors notably influenced duckling survival, including female age, the presence of ephemeral water within areas used by broods, distance from an anthropogenic source, distance moved, and the percentage of dense nesting cover within the route buffers.

Pasture type might not have been associated with duckling survival for several reasons. First, the categories were coarse (dairy farms with long grass or other livestock pastures with short grass) and individual livestock management regimes or even landowner differences could have obscured broad patterns in pasture type that might relate to duckling survival. In North America, lightly grazed pastures have higher nesting density, with nest success positively correlated with the amount of vegetation cover. However, higher nesting success is actually realised in the heavily grazed pastures when nests have similar levels of cover to the lightly grazed pastures (Warren et al., 2008). Similarly, waterfowl productivity in North America has been shown to increase in years when cattle pastures were recovering from grazing, and decrease in years when pastures were grazed, with an overall positive response in productivity noted when pastures were rotationally grazed, in comparison to season-long grazing (Gjersing, 1975; Holechek et al., 1982; Mundinger, 1976). However, in NZ the productive nature of the climate and landscape means pasture growth is much more rapid, and pastures are rotationally grazed in Spring and Summer at a much higher frequency of several weeks, as opposed to months or years. Consequently, relationships determined in North America between pasture length and duckling survival might not exist in NZ. Second, pasture length might affect duckling survival in opposing ways that, when combined, result in no net effect. For example, longer pastures in dairy management systems could reduce detection of ducklings by both aerial and mammalian predators (and people), but this advantage could be offset by ducklings expending more energy and effort keeping up with their broodmates when traversing long, thick grass, especially when young. Female mallards respond to feedback of sights and sounds of the brood, so if dense vegetation results in segregation of one or more ducklings, the female may not recognise this loss and proceed with the remaining brood. Conversely, sheep and deer pastures contain short grass facilitating detection by predators, but high visibility may also give the female time to react to predators. I did not track individual ducklings and was unable to determine the exact causes of duckling loss; thus, my hypothesis warrants further testing.

Consistent with previous North American studies (Devries et al., 2008; Devries et al., 2003; Kaminski et al., 2013; Mack & Clark, 2006; Rotella et al., 2003), female age had a positive impact on cumulative duckling survival, with ASY females having more than double the duckling survival of SY females. This is most likely due to the lack of brood-rearing experience of younger females (Rotella et al., 2003), and/or the increased amount of maternal investment by older females either in eggs (resulting in higher quality ducklings) or in brood-rearing; ASY females were generally larger and weighed more than SY females (mean mass $_{\text{ASY}}$ = 1,092 g, SE = 16.2, mean mass $_{\text{SY}}$ = 1,039 g, SE = 14.9) and may have additional energy with which to defend and brood ducklings (Devries et al., 2008; Kaminski et al., 2013). However, the majority of females caught in the walk-in baited traps were coated with varying degrees of mud due to wet, muddy conditions in traps, particularly those that had high trapping success.

Consequently, I thought female weights were not sufficiently accurate to include as an index of body condition in the model.

Permanent and semi-permanent wetlands are often present in brood-rearing areas. However, these water bodies provide poor quality habitat in terms of survival for mallard broods (Chouinard & Arnold, 2007). In North Dakota, duckling survival is positively correlated with the percentage of seasonal basins containing water, with use increasing during the wet period, suggesting the conservation and restoration of seasonal wetland habitat will benefit mallard productivity (Bloom et al., 2012; Hoekman et al., 2004; Krapu et al., 2006). In years when there is an abundance of seasonal ponds, broods in those North Dakota environments can avoid the permanent water bodies that have lower invertebrate food resources (Simpson et al., 2007) and that are preferred by predators such as mink (Krapu et al., 2004). In Southland, the presence of ephemeral water within the brood route during the first ten days post-hatch increased cumulative duckling survival by ~12% for SY females and ~15% for ASY females. This result is not surprising considering the abundant food resources available within temporary, shallow bodies of water across pastures, reducing feeding time and exposure to predators (Euliss Jr. et al., 1999; Krapu et al., 2006; Swanson et al., 1985). Weather covariates (hatch date, temperature and precipitation) did not appear in the most highly supported model. This may be due to low variation in values over the season as NZ has relatively mild weather conditions in comparison to North America. However, Gendron and Clark (2002) suggest that high quality wetland conditions throughout the breeding season are a better predictor of duckling survival than hatch date. The presence of ephemeral water bodies on brood routes during periods of high rainfall in this study supports their suggestion.

Duckling survival increased with distance from anthropogenic sources. Typically, houses and associated farm buildings come with increased levels of disturbance for broods (Korschgen & Dahlgren, 1992) and an increase in predator abundance (Thorington & Bowman, 2003).

The distance travelled overland by ducklings was negatively correlated with duckling survival. This is consistent with several studies (Ball et al., 1975; Bloom, 2010; Bloom et al., 2012; Mauser et al., 1994; Rotella & Ratti, 1992); but see (Dzus & Clark, 1997b; Talent et al., 1983). Overland movement may increase duckling vulnerability to predation, starvation, and becoming separated from their broodmates, particularly when movement is through more energy-expending dense cover. I was unable to evaluate this directly and cannot deduce whether duckling losses occurred before, during, or after movement. However, for younger and smaller ducklings in particular, overland movement is likely to be more energetically expensive (Anderson & Alisauskas, 2001; Talent et al., 1982). Chouinard and Arnold (2007) noted that short brood movements and small home ranges were correlated with areas where wetlands were mostly contiguous. During dry years, broods tend to travel further overland, compared to years with more water (Krapu et al., 2006). Consequently, the provision of seasonally flooded wetlands adjacent to nesting habitat may increase the survival of broods, by increasing proximal food availability and decreasing the necessary movement overland.

Females with broods tended to be observed not far from dense nesting cover, and when approached by investigators, females would head for dense cover. However, the percentage of dense nesting cover within a female’s route-buffer was negatively correlated with duckling survival. Other studies have observed similar results with an increase in grassland cover (Amundson & Arnold, 2011), upland perennial cover (Bloom, 2010), or forest cover (Simpson et al., 2007) negatively impacting duckling survival. This may be due to these habitats providing adequate cover (or perches) for predators (Bloom et al., 2013). Previous North American studies have demonstrated that a greater proportion of dense cover is positively associated with nesting success, suggesting a potential trade-off between optimal nesting and brood-rearing habitat requirements (Bloom, 2010; Greenwood et al., 1995; Stephens et al., 2005). In the Prairie Pothole Region of the North American Great Plains, females that avoided woody cover had the highest duckling survival, presumably by reducing predation from aerial predators (Bloom et al., 2013). However, in the Canadian Prairie Parklands, successful females had higher percentages of wood-shrub habitat and seasonal and semi-permanent water bodies within their home range (Mack & Clark, 2006). This suggests there are many confounding factors associated with different habitats and water bodies on brood survival. For this study, I classified dense nesting cover to include rank grass, ditch edges, woodlots, shelterbelts, and all other natural vegetation that was not grazed. It might be beneficial to separate these categories, measuring habitat at a much finer scale. For example, in North America, trees have been noted as perches for avian predators to scan the landscape, negatively correlating with duckling survival (Martin, 2009); however, the main avian predator in NZ is the swamp harrier *(Circus approximans)* which nests in grasslands near wetlands and may not require perches for hunting. Additionally, a positive correlation between nesting success and the proportion of dense nesting cover within the landscape suggests these areas may have higher brood density, which might correspond to lower duckling survival (Amundson & Arnold, 2011; Gunnarsson et al., 2006).

The 30 day cumulative duckling survival estimate is the first for mallards in NZ. Cumulative duckling survival, on average, was 31.3% (85% CI = 29.5-33.1%), which is lower than in south-central Saskatchewan, Canada where duckling survival ranged from 35.7% (90% CI = 27.5–45.6) in control sites to 57.3% (90% CI = 49.2–65.7) in predator removal sites (Pearse & Ratti, 2004). Similarly, Bloom (2010) found in the Canadian Prairie Pothole region, cumulative duckling survival averaged 52.3% (SE = 0.009) for decoy-trapped females with abdominal transmitters and 53.9% (SE = 0.014) for females that were nest-trapped with back-mounted transmitters. In Southland, the results are similar to estimates from California, where duckling survival averaged 24.8% (95% CI = 17.8–33.5) (Chouinard & Arnold, 2007), and to those in North Dakota ranging from 15.7% (85% CI = 8.4–25.2) in 2006 to 26.4% (85% CI = 19.3–35.5) in 2007 (Amundson & Arnold, 2011). Low duckling survival rates have been shown to be a limiting factor for population growth in some North American studies (Amundson et al., 2013; Coluccy et al., 2008).

The mothering ability of females differed hugely in the field, in terms of vigilance, brood care and female choices made in response to investigator presence. For example, some females preferred to stash their brood and exhibit flight behaviour, while others demonstrated a more cryptic approach, or tended to rush for the closest habitat containing dense cover. Anecdotally, one small group of females were observed resting on a ditch edge and remained unalarmed as a stoat ran along the water's edge and passed within 1 m of the ducks (C. Stewart, NZ Fish & Game, pers. comm.). These individual personality and behaviour traits can have a huge effect on duckling survival, and it would be interesting to consider personality in a future study. Additionally, I was restricted to using averages for several of the covariates (Dmoved, Dhouse, Dwater, Precip, Pasture) as Program MARK does not allow for a model with repeated measures.

Hence, it would be beneficial if a more complex model could take into account finer scaled change over time (i.e., daily) and details on the movements of broods, weather related variables and pasture information related to length, density and grazing pressure.

Management Implications

Recruitment of individuals into the population relies on young surviving the brood-rearing period and entering into adulthood (Baldassarre & Bolen, 2006). My results suggest that duckling survival is low in Southland, NZ, and management actions to improve duckling survival would help increase waterfowl populations in the area. While coarse measures of pasture management did not affect duckling survival in my study, my results still have several management implications. First, managers could improve habitat for brood survival by not installing sub-surface drainage through pastures, thus facilitating the presence of ephemeral and temporary water bodies during wet periods. Further, wetland creation and enhancement as well as increased connectivity between nesting habitat and brood-rearing habitat may result in lower rates of brood movement, which could increase duckling survival. Habitat enhancement may be especially beneficial in areas relatively far from anthropogenic structures (i.e., houses, sheds, roads). Brooding females selected for areas of dense nesting cover, with negative consequences for duckling survival. Further, dense nesting cover provides critical nesting habitat. Thus, managers may consider increasing patch sizes of dense nesting cover to reduce predator efficiency (Chalfoun et al., 2002), and employ predator removal in these areas to improve duckling survival. Because my habitat classification included multiple, highly variable types of unmanaged cover, a study investigating what specific fine-scaled factors in dense nesting habitat are impacting duckling survival would be informative for managers.

Challenges encountered during data collection led to several recommendations for future studies of this nature. First, observers should be well trained in all telemetry protocols as well as age classification of ducklings to ensure uniform data collection, especially for studies employing volunteers. Second, older broods often exhibit creching behaviour and additional time spent monitoring the brood without altering their behaviour might be necessary to determine how many ducklings belonged to an individual female. Techniques that individually mark ducklings (e.g., nape tags (Arnold et al., 2011); PIT tags) might provide a more accurate assessment of duckling survival, enable individual duckling covariates, and reduce issues related to creching. However, care should be taken that methods used to mark ducklings do not impact their survival (Amundson & Arnold, 2010). Third, results from my study suggest brood movements are relatively small, which suggests monitoring frequency could be reduced in future studies. Originally, there was concern that broods might make large overland movements that could lead to losing the signal of marked females if the time interval between resightings was too long. Lastly, it is critical to minimize investigator disturbance of late incubation nesting females and broods. Flushing hatching females from nests could reduce survival and persistent close resightings of broods by investigators could lead to females choosing to undergo movements more often or for longer distances, thus also leading to lower duckling survival. Resightings of females should be conducted from a distance that does not influence behaviour whenever possible.

Adult mallards and broods amalgamate on fresh rotationally-grazed dairy pasture.

Photo courtesy of Phil McCartney 2014

Chapter 3: Habitat Selection

3.1 Introduction

Animals often actively select a subset of resources from those that are available (i.e., those that an individual is able to access) by distinguishing among various environmental components and using features disproportionate to their availability (Block & Brennan, 1993). Individual choice of resources influences survival and reproduction (Jones, 2001; Kaminski & Elmberg, 2014; Schick et al., 2008), and therefore individual fitness, which determines the genetic representation of an individual's genes in subsequent generations (Mayr, 1970). It is often assumed that use of selected environmental variables by individuals accrues a fitness advantage, resulting in adaptation (Clark & Shutler, 1999; Martin, 1998), but this is frequently overlooked due to difficulties in assessing adaptive selection (Kaminski & Elmberg, 2014).

In North America, breeding mallards demonstrate selection of resources based on the proximity to wetlands and total wetland area (Beatty et al., 2014; Bloom et al., 2012; Walker et al., 2013a), especially seasonal or semi-permanent wetlands (Baldassarre & Bolen, 2006; Duebbert & Frank, 1984; Mauser et al., 1994). Brood-rearing females typically select areas with abundant invertebrate populations (an important food source for pre-fledged young) and dense vegetative cover, which allows broods to be secluded for most of the daytime (Baldassarre & Bolen, 2006). However, Bloom et al. (2013) demonstrated that females fledged more ducklings if they avoided woody perennial habitats, presumably because predators are associated with those areas. Selection of a successful nest-site binds pre-fledging ducklings to an area restricted by their post-hatch movement (Eichholz & Elmberg, 2014). Thus, it is unclear whether mallards consider proximity to adequate brood-rearing habitat when selecting a nest site, or are more concerned with characteristics that maximise nest success. Nevertheless, successful hatching is only one step toward recruiting individuals into the population (Baldassarre & Bolen, 2006).

New Zealand mallards display willingness to exploit abundant food sources such as cereal crops found around pastoral landscapes and anthropogenic sources (Balham, 1952; Williams & Basse, 2006). However, predator composition and abundance likely varies with proximity to urbanization, rural housing, and availability of dense cover such as that provided by hedge-lines or ungrazed riparian areas, and this might influence brood survival. Higher rates of nest predation have been demonstrated on artificial nests in areas of greater housing density (Thorington & Bowman, 2003). Competition exists between wildlife and a multitude of other land users for resources, meaning continual development of conservation strategies should be prioritized to reduce potential conflict (Jewell & Holt, 1981).

Habitat fragmentation, patch size, composition, and configuration might influence reproductive success of breeding waterfowl (Horn et al., 2005) and predation effects on reproduction are increasingly prevalent in habitats that are fragmented at the landscape scale (Stephens et al., 2003). Nest success in North American studies tends to be higher in areas with a higher percentage of grass habitat and fewer wetlands (Mack & Clark, 2006; Thompson et al., 2012), but the opposite trend has been observed for brood survival. Amundson et al. (2011) and Bloom et al. (2013) found duckling survival decreased as the amount of perennial cover increased in the landscape, but duckling survival was positively associated with wetland availability. To my knowledge, no published studies have focused on pastoral habitat selection and duckling survival, despite it being the dominant land use in much of New Zealand. To better understand the adaptive nature of breeding mallard habitat use, I evaluated habitat selection and subsequent effects on reproductive fitness of brood-rearing mallards in Southland, New Zealand. I hypothesized that brooding females, especially those that successfully fledged ducklings, would prefer dense nesting cover near sources of permanent water. Results from this study will help managers identify critical brood-rearing habitat for mallard duckling survival.

3.2 Methods

Details of the study species and methods for data collection and formatting of geospatial data sets are in Chapters 1 and 2, respectively. The study was undertaken in areas surrounding the Lochiel community in Southland, New Zealand 2014 (Chapter 2, Figure 2.1). Female mallards were marked with internal or external (prong-and-suture) radio-transmitters and monitored throughout the breeding season using both homing and null-peak telemetry methods. Females that successfully hatched a clutch were followed every day for the first ten days post-hatch, and every five days thereafter.

Total brood loss was determined by two consecutive sightings of a study female without any ducklings, whereas a female was deemed successful if one or more ducklings were still observed at 30 days post-hatch.

Habitat Use

Habitat selection is a hierarchical process whereby selection takes place on multiple scales, so the choice of study scale examined depends on the objectives and their alignment with management goals (Boyce, 2006; Buskirk & Millspaugh, 2006). I focused on the use of habitat components within the home range (i.e., third-order selection), but also examined selection at broader scales by comparing use to habitat composition within the study site (i.e., second-order selection) (Johnson, 1980). I used brood routes (i.e., buffered paths to consecutive brood locations) as a measure for ‘home range’ in analyses, instead of more typical minimum convex polygons (MCP), to maintain consistency with the data presented in Chapter 2.

Used Brood Routes

I created brood routes in ArcGIS (*v.* 10.2; ESRI Inc., Redlands, CA, USA) using the *Point to Line* feature, assuming straight line movement from the nest site to first female location and to subsequent known, consecutive locations until the female was last observed with ducklings, or rated as being ‘successful’ at 30 days post-hatch. I used the *Buffer* tool in ArcGIS to define the corridor of a certain width for linear routes, creating a 50 m buffer on either side of the segmented straight-line movements (100 m across). I then used the *Clip* tool to extract the information on habitat type from within the buffer. A 100 m buffer was approximately equal to the average distance moved per day. I made brood movement an artificial straight-line trajectory as the actual route taken was unknown but assumed to fluctuate around this line, presumably within the buffer.

Random Brood Routes

I compared habitat characteristics of used routes to three random routes for each female. I used the *movement.simplecrw* tool in Geospatial Modelling Environment (GME) (Beyer, 2012) to create random routes in ArcGIS that began at the nest site, and extended in daily segments that could initiate in any direction (0-360 degrees), but were restricted to remain within the 30 km^2 study area. While this restriction may create some bias in availability estimates, it allowed me to measure habitat characteristics within the area available to broods. Random routes were of equal buffer width, but daily segments were of random lengths within the maximum distance travelled in a day for each individual female. Random brood routes were completed with the same number of segments as the used brood routes, so segments were counted to the last time a female was seen with ducklings.

Habitat Variables

I digitised colour aerial photographs (cell size 0.4 m, resolution 1:1500) taken 5 February 2014 by New Zealand Aerial Mapping Ltd (NZAM) in ArcGIS and classified habitats into categories relevant to mallard brood ecology including: permanent water (ponds, streams and ditches), anthropogenic features (houses and roads), pastureland including dairy, sheep (and deer) pastures, and dense nesting cover (rank grass, road edges, woodlots, shelterbelts). I confirmed digitised habitat maps to verify layer accuracy through ground-truthing. I then used several ArcGIS tools to create covariate values including: the *Feature Vertices to Points* tool in combination with *Near* to obtain average distances to water and anthropogenic sources from each observed location, and the *Unsplit Line*, *Buffer,* and *Clip* tools to create buffers for used and random routes for each female and summarize the digitised habitat composition (see Chapter 2) within buffered routes as the proportion of the total route classified as each habitat type.

Statistical Analysis

I separated statistical analysis into two sections utilizing both compositional habitat analysis (Aebischer et al., 1993), and a resource selection function (RSF) (Boyce & McDonald). Firstly, I ran compositional analyses to determine if females were choosing a) specific brood sites within their buffered route, and b) brood routes disproportionately to those available across the entire study site. Compositional analysis ranks habitats according to their use within available habitats, but it does not allow the addition of covariates such as ‘distance to’ measures in the model (Aebischer et al., 1993). These analyses therefore only consider selection in relation to sheep and dairy pastures, and dense nesting cover. Secondly, I ran an RSF to determine if brood-rearing females were selecting for habitat at a rate different than that indicated by randomly selected routes. An RSF was chosen for its flexibility in accommodating both categorical and continuous variables as well as offering quantitative characterization of resource use (Boyce & McDonald, 1999). All analyses were performed in program R version 3.2.0 ("R Core Development Team," 2013).

Compositional Analysis

I ran a compositional analysis in order to rank habitats according to their use relative to those available within both the study area and used-route buffer. I used the *compana* function in R’s *adehabitatHS* package, v. 0.3.11 (Calenge, 2011) using both a Design II approach: where individuals are identified but available habitat is measured at the population level, and a Design III approach: where individuals are identified and available habitat is sampled for each individual (Manly et al., 2002). Habitat ranks were deemed significant (i.e., used more than expected based on availability) by a p-value ≤ 0.05 and output symbols (+ or -).

Resource Selection Functions

For the resource selection function (Boyce & McDonald, 1999; Manly et al., 2002), I used generalized linear mixed-effects models (GLMM) assuming a binomial distribution and included random effects identifying ducklings within a brood (Grueber et al., 2011). The advantage of this model is that it accounts for repeat measures on individuals (Grueber et al., 2011). I characterized used and available routes with a ‘1’ and ‘0’, respectively. I used a Design III approach where resource use is measured for each identified individual (Manly et al., 2002).

Only predictors that have strong biological reasoning were included in the global (i.e., most parameterized) model (Table 3.2) (Burnham & Anderson, 2002). I standardized all continuous predictor variables (mean = 0, SD = 1) to facilitate interpretation of coefficients on a common scale (Schielzeth, 2010). There was a strong negative correlation between habitat selection of sheep and dairy pastures, (i.e., if an individual was in one, they couldn’t also be in the other) meaning these covariates were included only in separate models as competing hypotheses. I included an interaction between brood success (i.e., whether or not at least one duckling survived to 30 days post-hatch) and habitat covariates to see if there were differences in selection between females that were successful in raising a brood, and those that were not. I used the *dredge* function in the *MuMIn* package (Barton, 2009) to evaluate model fit for all possible subsets of the global model using AIC_c (Akaike’s Information Criterion adjusted for small sample size) where the lowest AIC_c value represents the best fit to the data (Burnham & Anderson, 2002). I calculated variable importance for each parameter using the *importance* function in the *MuMIn* package (Barton, 2009). Variable importance is the sum of the AIC_c weight for models including a given parameter. I interpreted coefficient estimates from a model including the most supported (variable importance weight > 0.6) parameters (Nakagawa & Freckleton, 2011). I report coefficients with SE and predictions with 85% confidence intervals as they are more in line with AIC model selection (Arnold, 2010).

3.3 Results

From 5 July to 22 September 2014, I implanted 62 females with abdominal transmitters and captured and marked another 23 females on nests (see Chapter 2 for details). Three abdominally implanted females died within three days, likely due to wet, cold and muddy conditions during and just after marking. The remaining 82 females hatched 55 nests. Eight successful nests were censored from analyses due to various circumstances, including excessive investigator disturbance (n = 4), transmitter failure upon nest exodus (n = 2), female lost brood before first sighting (n = 1), and female never had her nest located but was rediscovered when the brood was ~ 10 days old (n = 1) which left 47 broods in my sample. Of the habitat categorized within the study area, 8.9% was ‘dense nesting cover’ (i.e., hedge rows, road verges, ditch edges, wetland margins), 45.7% was short sheep or deer farm pasture and the remaining 45.4% was long dairy pastures, with varying degrees represented in each females used-route buffer (Appendix A, Table A2.3).

Compositional analysis

Compositional analyses indicate that brood-rearing females selected dense nesting cover more strongly than sheep or dairy pastures, at both the brood route and study area scale (Table 3.1). Further, short-grass sheep pasture was slightly more prevalent within brood route buffers than was long-grass dairy pasture. However, within the home range scale (third-order selection), brood-rearing females were located within long dairy pastures more often than short sheep pasture.

Table 3.1: The compositional analyses ranking matrices evaluating (left) the percentage of habitat available in the study area compared to used-route buffers for female mallards (Wilks λ = 0.3184, p = 0.002); and (right) the observed locational point data of female mallards with broods in relation to what is available within each females used-route buffers (Wilks λ = 0.1775, p = 0.002) in Southland, New Zealand 2014. Habitats included were sheep and dairy pastures, and dense nesting cover (DNC). Wilks λ examines the difference between the means of used and available habitat. A ‘+’ represents when a habitat (row) is used more than another habitat (column), while the ‘-’ represents otherwise. Significance level is denoted by the number of symbols (i.e., +++ is more significant than +).

	Study site scale **Used-route buffer** **(2nd order of selection)**			**Home range scale** **Locational point data** **(3rd order of selection)**		
	DNC	Sheep	Dairy	DNC	Sheep	Dairy
DNC	0	+++	+++	0	+++	+++
Sheep	---	0	+	---	0	-
Dairy	---	-	0	---	+	0

Resource selection

Seven models received equivalent support (i.e., $\Delta AIC_c < 2$) (Appendix B, Table B3.5), however, the best supported parameters according to variable importance were dairy pasture, distance to anthropogenic sources, and distance to dense nesting cover that varied by brood fate (Table 3.3). This model explained 67% of the variance in the data (adjusted R^2). The results demonstrate that females tended to select for an increased proportion of dairy pastures within the used brood route (Figure 3.1). Additionally, females selected for areas further from anthropogenic structures, and preferentially occupied areas near dense nesting cover (Figure 3.2 and 3.3). All females utilized areas within 75 m of dense nesting cover (mean = 14.9, SD = 15.3, range = 0–75 m) and within 490 m of anthropogenic sources (mean = 234.5 m, SD = 110.2, range = 56.6–490 m) whereas the average distance in random routes to dense nesting cover was 44 m

(SD = 21.5, range = 1–150 m) and to anthropogenic sources was 243 m (SD = 203.2, range = 0–1417 m) in the immediate landscape. Further, unsuccessful females utilized habitat nearer to dense nesting cover at greater rates than did successful females (Figure 3.3) and proximity to dense nesting cover used by successful females was more variable (i.e., had wider confidence intervals).

Table 3.2: Importance weight of variables collected for brood-rearing female mallards selecting habitat along a brood route in Southland, New Zealand, 2014.

Parameter	**Importance Weight**
Distance to DNC	1
Distance to DNC by brood fate	1
% of dairy pasture in route buffer	0.97
Distance to anthropogenic sources	0.76
Distance to water	0.53
Distance to anthropogenic sources by brood fate	0.31
% of dairy pasture in route buffer by brood fate	0.29
Distance to water by brood fate	0.16
% of sheep pasture in route buffer	0.02
% of sheep pasture in route buffer by brood fate	<0.01

*DNC = dense nesting cover

Table 3.3: Generalized linear mixed model coefficients from a resource selection function evaluating parameters associated with the probability of use for selection of habitat along a brood route (i.e., distance to dense nesting cover, distance to dense nesting cover by brood fate, percentage of dairy pasture in a females' route buffer and distance to anthropogenic sources) for mallard females in Southland, New Zealand 2014.

Parameter	**Estimate**	**Standard Error (SE)**
Intercept	-2.07	0.35
Distance to DNC	-1.83	0.43
Distance to DNC by brood fate $_{\text{(Successful)}}$	-3.92	1.22
% of dairy pasture in route buffer	1.05	0.33
Distance to anthropogenic sources	0.53	0.28

*DNC = dense nesting cover

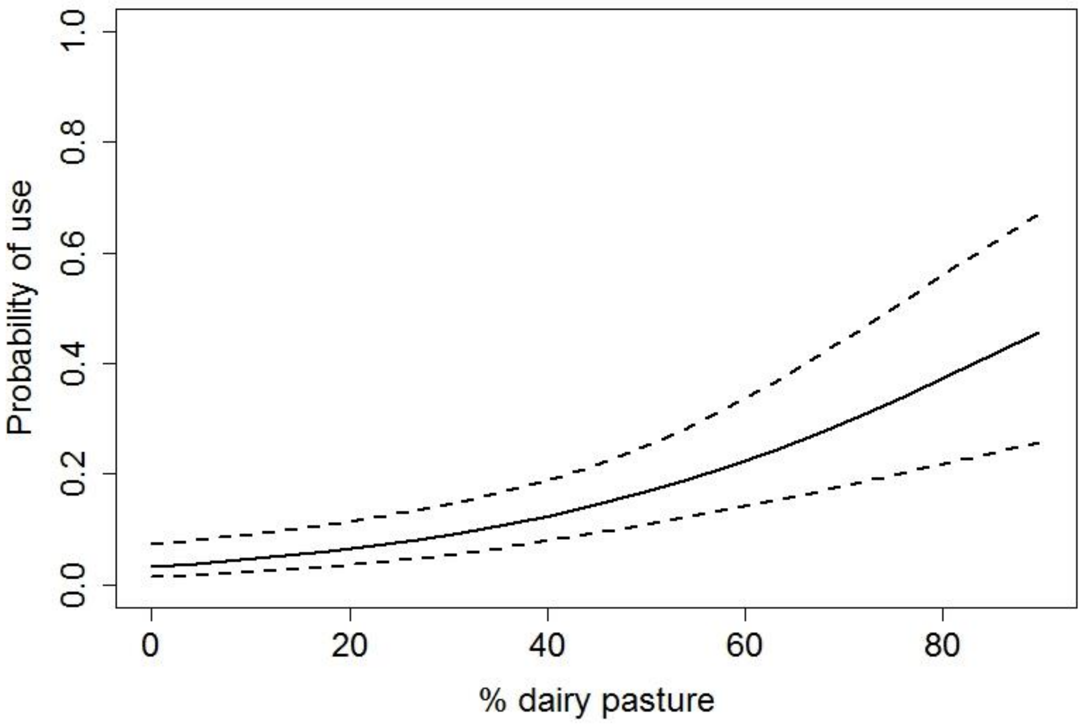

Figure 3.1: The probability a female mallard selected a brood route (with a 50 m radius buffer) relative to the amount of dairy pasture within the brood route in Southland, New Zealand 2014. Mean dairy pasture area per brood route was 42.9%. All other covariates are held to mean values (distance to dense nesting cover = 14.9 m, distance to anthropogenic sources = 234.5 m, initial brood size = 9.06 ducklings). Dashed lines represent 85% confidence intervals.

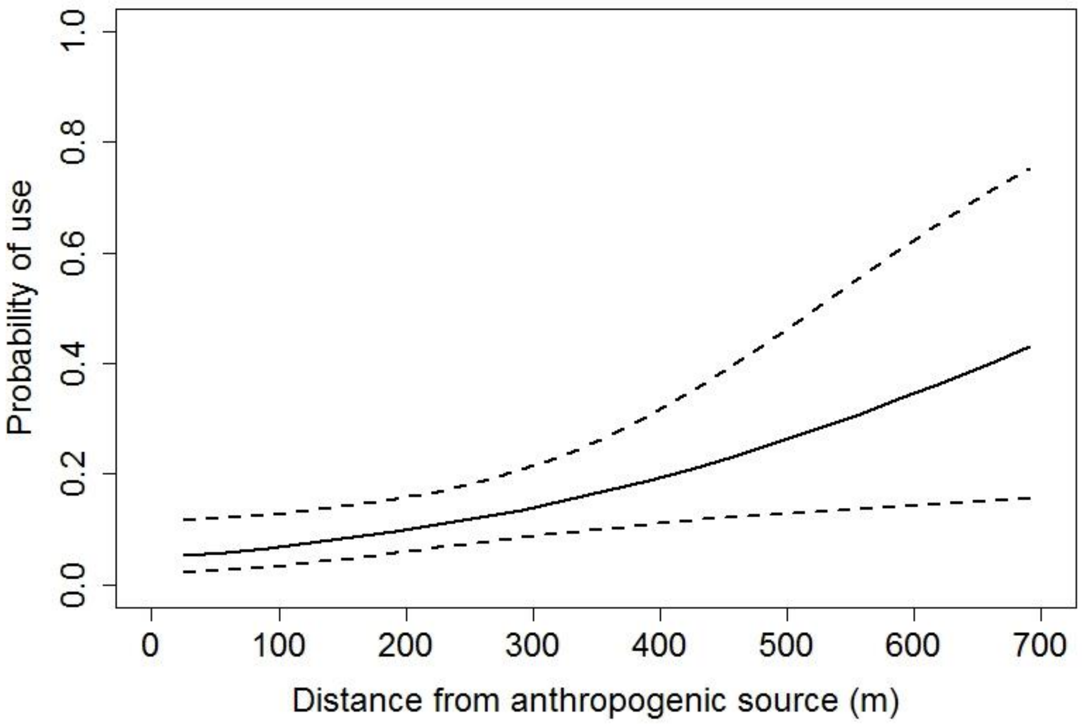

Figure 3.2: The probability of female mallard with a brood used a route in relation to distance (m) from anthropogenic sources (e.g., houses, roads) in Southland, New Zealand 2014. Mean distance from anthropogenic sources across the used brood routes was 234.5 m. All other covariates are held to mean values (distance to dense nesting cover = 14.9 m, area of dairy pasture within the used brood route = 42.9%, initial brood size = 9.06 ducklings). Dashed lines represent 85% confidence intervals.

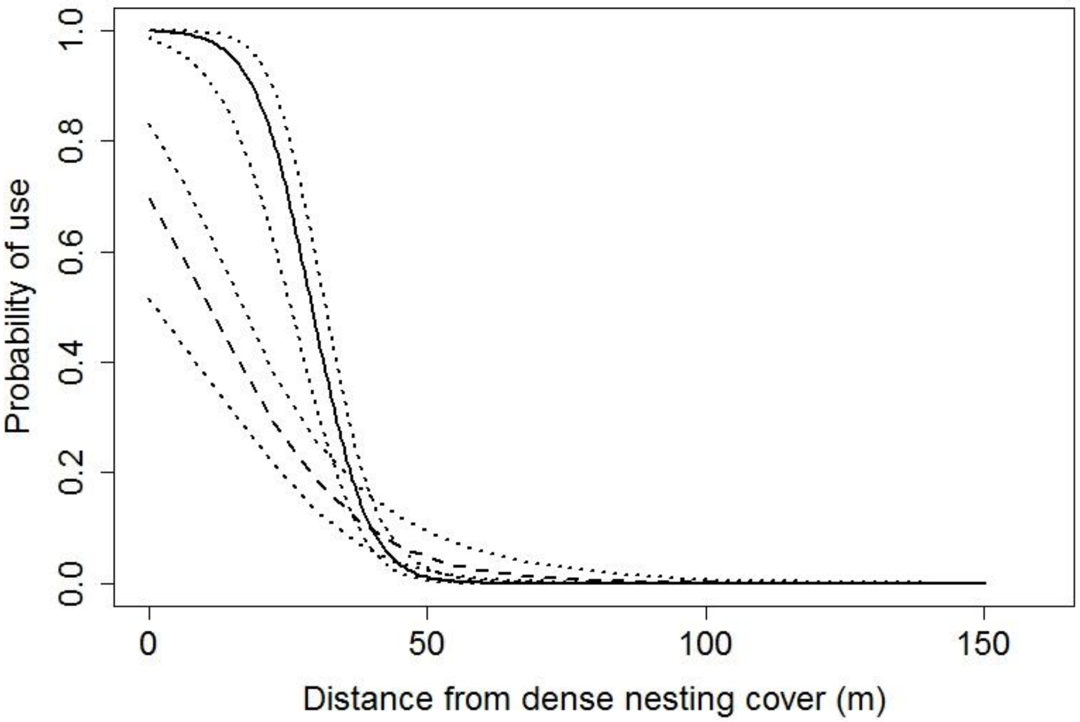

Figure 3.3: The probability a female mallard in Southland, New Zealand 2014 used a route relative to the distance to dense nesting cover for broods that were ultimately successful (i.e., at least one duckling survived to 30 days post-hatch; long dashed line) or experienced total brood failure (solid line). Mean distance from dense nesting cover for used brood routes was 14.1 m (SD = 12.2) for successful females and 16.1 m (SD = 19.1) for unsuccessful females. All other covariates are held to mean values (distance to anthropogenic sources = 234.5 m, area of dairy pasture within the used brood route = 42.9%, initial brood size = 9.06 ducklings). Dotted lines represent 85% confidence intervals.

3.4 Discussion

My results emphasize the need to take into account both habitat selection (i.e., species distribution within habitats) and individual fitness (i.e., survival and reproduction) to understand the effects of habitat on population dynamics of waterfowl (Aldridge & Boyce, 2013; Poysa, 2001). Female mallards show strong habitat selection for dense nesting cover during the brood-rearing period in Southland, New Zealand 2014. However, results were not consistent with my predictions that successful females would have greater selection for dense nesting cover close to sources of permanent water.

Wetlands and dense nesting cover provide both protection from inclement weather and an energy-rich source of food (Beatty et al., 2014; Tidwell et al., 2013). In the Prairie Pothole region (PPR), landscapes with a higher density of small to mid-sized wetland basins and a greater proportion of herbaceous perennial vegetation held the most broods (Walker et al., 2013a). Further, Bloom et al. (2012) found duckling survival increased with the proportion of wetlands with a central expanse of water and a peripheral ring of emergent vegetation within a 500 m radius buffer of the brood route. Contrary to these international studies, NZ mallard females did not strongly select for areas near water sources. However, this could be due to the extensive availability of ephemeral water in pastures after any significant rainfall event. The breeding season coincides with the rainy season in Southland and thus, ephemeral water sources were common during my study. However, these bodies of water were not accounted for in my analysis due to their temporary and unpredictable occurrence.

Females strongly selected for dense nesting cover, which included any rough vegetation around ditches, ponds, wetlands, and wood lots, shelterbelts and road edges. However, successful females selected dense nesting cover at a lower rate than did unsuccessful females (Figure 3.3). These findings are consistent with Bloom et al. (2012) who found survival of older ducklings was negatively correlated with managed hayland in Prairie Canada. Similarly, Amundson and Arnold (2011) found mallard duckling survival decreased with increased unmanaged grassland in the USA. The relationship between female selection of dense nesting cover and brood survival could be a function of predator abundance, patch size, edge effects and configuration (patch shape and location within the landscape) (Horn et al., 2005). Dense nesting cover represented only 8.95% (Appendix A, Table A2.3) of my study site, perhaps offering corridors for predator movement, species concealment (for both predator and prey), and suitable habitat for predator den sites in comparison to the surrounding pasture. These factors could potentially lead to high predator densities in dense nesting cover, further magnified by small patch sizes.

Duckling predation might increase with an increase in habitat fragmentation due to an increase in foraging efficiency within these smaller patches, and/or combined with a higher prey or predator concentration (Clark & Nudds, 1991). In the PPR, low rates of nest success have been associated with small, narrow areas of habitat, including those patches around wetlands compared to idle grassland and planted cover habitats (Klett et al., 1988). Further, nest predation increases in fragmented landscapes, particularly those fragmented by agricultural production, possibly due to the provision of additional prey food sources (Chalfoun et al., 2002). However, various nest predators respond differently to habitat fragmentation, and while I recognise predators responsible for nest predation are not always important brood predators they are likely similar in terms of both profitability for a predator and the opportunistic encounter rate. Consequently, I suggest that further research is needed to examine the predator communities affecting mallard recruitment in Southland.

Southland female mallards’ selection for areas near dense nesting cover might be an artefact of nest site selection. Most (93.2%) females nested in dense nesting cover despite it only representing 8.9% (Appendix A, Table A2.3) of available habitat. Thus, examining survival from nesting to fledging is necessary to fully evaluate the fitness consequences of habitat selection. My results suggest that habitat selection was not adaptive for at least part of the breeding cycle; that is, female habitat selection of dense nesting cover was associated with lower brood survival.

At the study-site scale, females selected brood route areas that contained a higher proportion of sheep pasture than dairy pasture based on availability. Conversely, within individual used-route buffers, while females might have had slightly more sheep pasture present within their route, they tended to be found within dairy pastures at a higher rate than predicted based on availability. This could be related to total landscape composition, such as disproportionately more wetlands, or dense nesting cover located near or within dairy pastures. For example, while there are no specific requirements in New Zealand to fence off property waterways, there is a national expectation to have dairy cattle excluded from streams, in part from the creation of the Dairying and Clean Streams Accord, an agreement between the Ministry for Primary Industries, the Ministry for the Environment, Fonterra, and Local Government New Zealand (regional councils) (MPI, 2013). It is a voluntary environmental initiative stating that any waterway ‘deeper than a red band gumboot’ (ankle deep), ‘wider than a stride’ (1 m) and permanently flowing, should be fenced off from dairy cattle. Cattle can be excluded with only one electric fence strand, while sheep and/or deer require more intensive fencing. Consequently, a generalization is that dairy properties tend to have more fenced off dense nesting cover habitat surrounding streams frequented by mallards than are found on sheep properties. Additionally, females may be more inclined to select long-grass dairy pasture because dairy pastures are rotationally grazed resulting in lower disturbance rates in comparison to short-grass sheep pastures that tend to be set stocked over the mallard brood-rearing period. Also, once a long-grass dairy pasture had been rotationally grazed, the residual pasture still provided much more cover for females with broods than what was available within continually grazed sheep pastures. Further, my field observations suggest that mallards are particularly attracted to dairy pastures immediately following mowing or grazing disturbance. Presumably these activities increase the accessibility to invertebrates (i.e., earthworms) and other food sources commonly consumed by mallard broods.

A potential challenge to any research involving habitat selection is the determination of not only what habitat is available, but also that which is accessible to an individual (Davis et al., 2014; Johnson, 1980). Habitat use might not necessarily indicate the preferred habitat or quality of habitat, but rather what is truly accessible after external pressures such as predation risk, inter- or intra-specific competition and/or social factors related to higher population density are accounted for (Kaminski & Elmberg, 2014; Lele et al., 2013). While a more complete analysis of habitat use would include these possible interactions (Sinclair et al., 2006), females and broods were observed creching with other mallard broods on multiple occasions, other species were not observed defending territory from mallards and brooding females used all coarsely defined habitats within my study area suggesting habitats were accessible to broods and exclusion through competition was unlikely.

Management Implications

Without evaluating fitness consequences to mallard habitat selection, managers might incorrectly identify appropriate habitat and management activities, resulting in inefficient use of resources (Aldridge & Boyce, 2013; Martin, 1998). This study demonstrates that brood-rearing females are indeed selecting for dense nesting cover and long-grass dairy pasture. However, small fragments of dense nesting cover could be acting as reproductive sinks – where females are attracted to areas with dense nesting cover for brood protection, but use of these areas results in greater brood failure. Predators might be more abundant, or better able to stalk and kill ducklings, in dense nesting cover than in pastures. Thus, protecting and enhancing unmanaged perennial cover, especially grasslands, will attract broods. However, predator removal focused on dense nesting cover might be required to realize benefits to broods from these habitats and act to dilute predator effects on duckling survival (Amundson & Arnold, 2011; Garrettson & Rohwer, 2001). Overall, broods used dairy pastures more often than sheep pastures. Thus, any concern of managers regarding the shift in pastoral management away from sheep and toward dairy could ultimately benefit brood survival, although further research into relative food availability in each pasture type, and the association between pasture type and water availability is needed to fully evaluate this relationship. As my study questions are focused more on pastoral habitat selection, the dense nesting cover classifications I used were quite coarse. Hence, future studies should focus on separating dense nesting cover into habitats of a finer scale, such as: shelterbelt hedgerows, rank grass, wetland periphery, fenced waterways and woodlots. Further studies should also evaluate predator abundance and distribution in relation to these specific habitat features so results could be used to best apply predator control.

A mallard brood joined by two ducklings of a younger age class in Southland, New Zealand, 2014.

Photo courtesy of Phil McCartney 2014

Chapter 4: Summary

In New Zealand, cultural and recreational values surround the introduced mallard, which makes up the majority of the bag for most gamebird hunters (Barker, 2006). In order to manage any wildlife population sustainably in a human-dominated ecosystem, it is necessary to gain an understanding of the underlying vital rates of the population. A challenge for wildlife managers is to understand the drivers of variation in reproduction and survival when there are many factors that may impact individuals (Sargeant & Raveling, 1992).

Mallard productivity is dependent on sequential but distinct events: the successful hatching of a clutch, followed by the survival of any hatched ducklings to fledgling. Nest success (the probability that at least one egg hatches from a clutch) is the most important vital rate influencing mallard recruitment in North America (Greenwood et al., 1995; Hoekman et al., 2002; Johnson et al., 1992; Walker et al., 2013b); the next most important vital rate is duckling survival and adult female survival during the breeding season (Howerter et al., 2014). Nevertheless, duckling survival can be a limiting factor in some populations (Amundson & Arnold, 2011; Coluccy et al., 2008; Howerter et al., 2014). The selection of resources can influence both of these vital rates. Currently, we have limited knowledge of the breeding ecology, reproductive success and habitat use of mallards in New Zealand.

Although a significant proportion of waterfowl habitats exist within agricultural enterprises, agriculture and wildlife can have antagonistic needs, whereby waterfowl habitat quality and availability can be compromised by some agricultural practices (Kadlec & Smith, 1992). In recent years, hunters in Southland, New Zealand, have expressed concern over the ongoing conversion of sheep and deer farms to dairying systems, and its possible influence on mallard brood survival and subsequent population trends. To address this issue, I collected data on 85 mallard females in Southland, New Zealand in 2014 and sought to answer several questions relating to duckling survival and the adaptive nature of habitat selection during brood-rearing.

First, I evaluated sources of variation in survival of mallard ducklings, considering the effects of habitat, weather, maternal investment, and brood characteristics, with an emphasis on pasture management systems (Chapter 2). Second, I evaluated habitat selection by brood-rearing females, and more importantly, quantified variation in habitat selection in relation to female success in raising a brood to 30 days of age. Any such variation could provide a basis for adaptive selection, with females who consistently choose certain habitat features being more likely to raise a brood to the fledgling stage (Chapter 3).

I found that duckling survival was higher for ducklings raised by a female beyond its second year, when ephemeral water was present in the areas used by the brood during the first ten days, and as ducklings moved further from anthropogenic sources. Conversely, duckling survival decreased for broods that had to move greater distances overland, and for broods that had a higher percentage of dense nesting cover along that brood route. Pasture type did not have a significant effect on duckling survival in Southland. However, the nature of losses might vary by pasture type such that duckling survival may be counterbalanced in both systems. For instance, long grass might allow adequate cover from predators, but could impede travel, being more energetically expensive for young ducklings to traverse. In contrast, short grass might expose more available sources of food, but allows no protection from predation. Weather variables (date, precipitation, temperature) did not explain any significant variation in duckling survival. In North America, duckling survival has been shown to decrease when temperatures drop below 10°C (Pietz et al., 2003). While temperatures dropped below 10°C during the study period, any affect might have been offset by the benefit of ephemeral water and abundant food resources that become available with periods of high precipitation, which were often associated with lower temperatures.

To evaluate habitat selection, I used a compositional analysis and resource selection function, discovering that brood-rearing females preferentially use the habitat provided by dairy pasture and dense nesting cover. In concordance with the duckling survival results, females that successfully raised a brood selected habitat post-nesting that was further from dense nesting cover than did unsuccessful females.

My results suggest that the type of agricultural system (sheep vs. dairy) does not affect duckling survival. This is a positive result for managers because the prevalence of one or other farming system is unlikely to be influenced by any benefit to mallard productivity. Of interest is the decrease in duckling survival as the proportion of dense nesting cover increases within a brood route. This suggests that habitat selection by brood-rearing females is not adaptive, at least for part of the breeding cycle when female selection of dense nesting cover was associated with lower brood survival. I suggest the detrimental effect associated with increasing amounts of dense nesting cover and proximity is an association with mammalian predators. In particular, the stoat *(Mustela erminea)*, weasel *(M. nivalis)*, ferret *(M. putorius furo)* and feral cat *(Felis catus)* are likely candidates with research necessary on their density and habitat use during the mallard brood-rearing period. The majority (93.2%) of nests were found within dense nesting cover and roughly 20% of the marked nesting females were killed on the nest, with most providing evidence of predator wounds at necropsy. However, only one brooding female died in my study. It might seem counterintuitive that females are selecting dense nesting cover if it results in reduced brood survival, but this could be influenced by another pressure, such as seeking protection from the weather, or cover from aerial predators like the swamp harrier *(Circus approximans)*. During the field season I observed a swamp harrier attack and wound a female mallard accompanied by a drake occupying a water trough in an open pasture. Similar results have been found in North America with an increase in grassland cover (Amundson & Arnold, 2011; Bloom, 2010) or forest cover (Simpson et al., 2007) decreasing duckling survival.

Understanding how duckling survival is influenced by edge effects, patch size and patch configuration within the landscape would be beneficial for management, although these are likely to be complex interactions (Horn et al., 2005). For example, an increase in fragmentation of dense nesting cover might increase predation effects, particularly if foraging efficiency of predators is increased as well (Clark & Nudds, 1991). This might be further enhanced if small patches are in a linear configuration. In the Prairie Pothole Region, the daily survival rate of nests was greater in larger patches of habitat, with red fox *(Vulpes vulpes),* in particular, being more active in smaller patches (Sovada et al., 2000). Sovada et al. (2000) suggested that small, isolated habitat patches (such as found in my study area) without predator management strategies might have negative effects on duck populations by attracting breeding ducks, but resulting in low productivity. However, the waterfowl in North America have a very different suite of predators than those present in New Zealand, warranting further research on the topic.

Understanding the intertwining relationship between patch size, predator saturation and the effect of edges could help explain the association between duckling survival and dense nesting cover. I suggest future research should be focused on predator abundance, distribution, and use in patches of dense nesting cover segregated at a finer scale within the landscape (i.e., rank grass, shelterbelts, hedgerows, riparian edges). Edges have been proposed as being travel pathways for predators (Bider, 1968). For example, in Otago pastoral habitat, ferrets have been found to concentrate activity along habitat edges, particularly in the ecotone between pasture and vegetative cover, and fence lines (Baker, 1989; Ragg & Moller, 2000). Ferrets also use vegetative cover for denning, displaying a preference for anthropogenic sources (i.e., sheds, hay barns) with an avoidance of open pasture habitat (Ragg & Moller, 2000). Rodents are in higher abundance around agricultural sheds, and consequently attract the sheltered denning of associated predators close to a high source of prey (Ragg & Moller, 2000).

Feral cats typically den in agricultural buildings or in dense vegetative cover. Females with kittens denning in agricultural buildings have larger home ranges, utilizing drains and other cover for hunting (Langham, 1991). In contrast, female cats that den in dense vegetative cover can hunt during the day or night, allowing for smaller home ranges closer to high sources of prey (Langham, 1991). A study of feral cats, stoats and ferrets on the Otago peninsula showed that these predators select for long grass habitat over pasture, suggesting that the vegetative 'buffer zones' created by retiring pasture surrounding yellow-eyed penguin *(Megadyptes antipodes)* colonies were actually attracting predators instead of acting as a deterrent (Alterio et al., 1998). If duckling survival is negatively affected by either high abundance of mammalian predators during the brood-rearing period, or the use of small patches of linear habitat increasing foraging efficiency, then this is a factor that managers can manipulate with predator trapping programs, which in turn might have cascading benefits throughout the whole ecosystem.

The presence of ephemeral water bodies in brood-rearing areas is important for both females and broods in providing an abundance of high quality food (Batt et al., 1992), especially when within close proximity to nesting areas, to minimize duckling mortality during overland travel (Ball et al., 1975). Based on my estimates of cumulative 30 day duckling survival, the presence of ephemeral water bodies are important for duckling survival. It seems probable that this benefit is a result of an increase in the availability of invertebrates, particularly those in the Class Oligochaeta (i.e., earthworms) (pers. obs., Appendix C, Figure C4.1). However, this understandably conflicts with the maximization of land used for agricultural production. Managers should consider promoting wetlands that allow the water levels to be altered seasonally, to mimic ephemeral water bodies, rather than current open water wetlands that tend to have static water levels. Additionally, my results suggest that it would be advantageous for hunters to put effort into predator control measures, particularly within areas of dense nesting cover. Further, duckling survival decreased when broods were in closer proximity to anthropogenic structures – this might be due to factors influencing disturbance, or through predator concentrations near human structures. Further research on predator abundance, home range and patterns of habitat use should be used to inform a comprehensive approach to regional predator management. Finally, results presented here will feed into nationwide population models that will inform managers as to whether duckling survival rates in Southland are sufficient to maintain the mallard population at harvestable levels.

Stoat (center) observed travelling along habitat features in the study area, Southland, New Zealand, 2014.

Photo courtesy of Phil McCartney 2014

References

Aebischer, N. J., Robertson, P. A., & Kenward, R. E. (1993). Compositional analysis of habitat use from animal radio-tracking data. *Ecology, 74*(5), 1313-1325.

Afton, A. D., & Paulus, S. L. (1992). Incubation and brood care. In B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, & G. L. Krapu (Eds.), *Ecology and management of breeding waterfowl* (pp. 62-108). Minneapolis, MN, USA: University of Minnesota Press.

Aldridge, C. L., & Boyce, M. S. (2013). Accounting for fitness: combining survival and selection when assessing wildlife-habitat relationships. *Israel Journal of Ecology & Evolution, 54*(3-4), 389-419.

Alterio, N., Moller, H., & Ratz, H. (1998). Movements and habitat use of feral house cats *Felis catus*, stoats *Mustela erminea* and ferrets *Mustela furo*, in grassland surrounding Yellow-eyed penguin *Megadyptes antipodes* breeding areas in spring. *Biological Conservation, 83*(2), 187-194.

Amundson, C. L., & Arnold, T. W. (2010). Effects of radiotransmitters and plasticine bands on mallard duckling survival. *Journal of Field Ornithology, 81*(3), 310-316.

Amundson, C. L., & Arnold, T. W. (2011). The role of predator removal, density-dependence, and environmental factors on mallard duckling survival in North Dakota. *The Journal of Wildlife Management, 75*(6), 1330-1339.

Amundson, C. L., Pieron, M. R., Arnold, T. W., & Beaudoin, L. A. (2013). The effects of predator removal on mallard production and population change in northeastern North Dakota. *The Journal of Wildlife Management, 77*(1), 143-152.

Anderson, V. R., & Alisauskas, R. T. (2001). Egg size, body size, locomotion, and feeding performance in captive king eider ducklings. *The Condor, 103*, 195-199.

Arnold, T. W. (2010). Uninformative parameters and model selection using Akaike's information criterion. *Journal of Wildlife Management, 74*(6), 1175-1178.

Arnold, T. W., Roche, E. A., Devries, J. H., & Howerter, D. W. (2012). Costs of reproduction in breeding female mallards: predation risk during incubation drives annual mortality. *Avian Conservation and Ecology, 7*(1).

Arnold, T. W., Shizuka, D., Lyon, B. E., Pelayo, J. T., Mehl, K. R., Traylor, J. J., . . . Amundson, C. L. (2011). Use of nape tags for marking offspring of precocial waterbirds. *Waterbirds, 34*(3), 312-318.

Bacon, B. R., & Evrard, J. O. (1990). Horizontal mist net for capturing upland nesting ducks. *North American Bird Bander, 15*(1), 18-19.

Baker, G. (1989). *Aspects of mammalian predator ecology co-inhabiting giant skink habitat.* (MSc), University of Otago, Dunedin, New Zealand.

Baldassarre, G. A., & Bolen, E. G. (2006). *Waterfowl Ecology and Management* (Second ed.). Malabar, Florida, USA: Krieger Publishing Company.

Balham, R. W. (1952). Grey and mallard ducks in the Manawatu district, New Zealand. *The Emu, 52*, 163-191.

Ball, I. J., Gilmer, D. S., Cowardin, L. M., & Riechmann, J. H. (1975). Survival of wood duck and mallard broods in North-Central Minnesota. *The Journal of Wildlife Management, 39*(4), 776-780.

Barker, R. (2006). National gamebird hunter survey results 2005. Unpublished. 30 pgs.

Barton, K. (2009). MuMIn: multi-model inference. (Version R Package version 1.13.4). http://mumin.r-forge.r-project.org/.

Batt, B. D. J., Afton, A. D., Anderson, M. G., Ankney, C. D., Johnson, D. H., Kadlec, J. A., & Krapu, G. L. (1992). *Ecology and Management of Breeding Waterfowl*. MN: University of Minnesota Press.

Beatty, W. S., Webb, E. B., Kesler, D. C., Raedeke, A. H., Naylor, L. W., & Humburg, D. D. (2014). Landscape effects on mallard habitat selection at multiple spatial scales during the non-breeding period. *Landscape Ecology, 29*(6), 989-1000.

Beyer, H. L. (2012). Geospatial modelling environment (Version 0.7.3.0). www.spatialecology.com/GME.

Bider, J. R. (1968). Animal activity in uncontrolled terrestrial communities as determined by a sand transect technique. *Ecological Monographs, 38*(4), 269-308.

Bishop, C. J., White, G. C., & Lukacs, P. M. (2008). Evaluating dependence among mule deer siblings in fetal and neonatal survival analyses. *Journal of Wildlife Management, 72*(5), 1085-1093.

Block, W. M., & Brennan, L. A. (1993). The Habitat Concept in Ornithology. In D. M. Power (Ed.), *Current Ornithology* (Vol. 11, pp. 35-91): Springer US.

Bloom, P. M. (2010). *Mallard duckling survival and habitat selection in the Canadian Prairie Pothole Region.* (MSc), University of Saskatchewan, Saskatoon.

Bloom, P. M., Clark, R. G., Howerter, D. W., & Armstrong, L. M. (2012). Landscape-level correlates of mallard duckling survival: Implications for conservation programs. *The Journal of Wildlife Management, 76*(4), 813-823.

Bloom, P. M., Clark, R. G., Howerter, D. W., & Armstrong, L. M. (2013). Multi-scale habitat selection affects offspring survival in a precocial species. *Oecologia, 173*(4), 1249-1259.

Blums, P. N., Reders, V. K., Mednis, A. A., & Baumanis, J. A. (1983). Automatic drop-door traps for ducks. *The Journal of Wildlife Management, 47*(1), 199-203.

Bortolotti, G. R., Marchant, T. A., Blas, J., & German, T. (2008). Corticosterone in feathers is a long-term, integrated measure of avian stress physiology. *Functional Ecology, 22*(3), 494-500.

Boyce, M. S. (2006). Scale for resource selection functions. *Diversity and Distributions, 12*(3), 269-276.

Boyce, M. S., & McDonald, L. L. (1999). Relating populations to habitats using resource selection functions. *TREE, 14*(7), 268-272.

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference: A practical information-theoretic approach* (Second ed.). New York, USA: Springer.

Buskirk, S. W., & Millspaugh, J. J. (2006). Metrics for studies of resource selection. *The Journal of Wildlife Management, 70*(2), 358-366.

Caithness, T. (1982). *Gamebird Hunting: problems, questions and answers*. Wellington, NZ: Wetland Press.

Calenge, C. (2011). Exploratory analysis of the habitat selection by the wildlife in R: the adehabitatHS package (Version 0.3.11). http://cran.auckland.ac.nz/web/packages/adehabitat/adehabitat.pdf.

Carney, S. M., & Geis, A. D. (1960). Mallard age and sex determination from wings. *The Journal of Wildlife Management, 24*(4), 372-381.

Chalfoun, A. D., Thompson III, F. R., & Ratnaswamy, M. J. (2002). Nest predators and fragmentation: a review and meta-analysis. *Conservation Biology, 16*(2), 306-318.

Chouinard, M. P., & Arnold, T. W. (2007). Survival and habitat use of mallard (Anas platyrhynchos) broods in the San Joaquin Valley, California. *The Auk, 124*(4), 1305-1316.

Clark, R. G., & Nudds, T. D. (1991). Habitat patch size and duck nesting success: the crucial experiments have not been performed. *Wildlife Society Bulletin, 19*(4), 534-543.

Clark, R. G., & Shutler, D. (1999). Avian habitat selection: Pattern from process in nest-site use by ducks? *Ecology, 80*(1), 272-287.

Cleary, E. C. (1994). *The handbook: Prevention and control of wildlife damage*. Ohio, USA.

Cochrane, G. R. (1960). The Winton district, Southland. *New Zealand Geographer, 16*(2), 146-169.

Coluccy, J. M., Yerkes, T., Simpson, R., Simpson, J. W., Armstrong, L., & Davis, J. (2008). Population dynamics of breeding mallards in the Great Lakes States. *Journal of Wildlife Management, 72*(5), 1181-1187.

Cox Jr., R. R., Hanson, M. A., Roy, C. C., Euliss Jr., N. H., Johnson, D. H., & Butler, M. G. (1998). Mallard duckling growth and survival in relation to aquatic invertebrates. *The Journal of Wildlife Management, 62*(1), 124-133.

Critchfield, H. J. (1954). The growth of pastoralism in Southland, New Zealand. *Economic Geography, 30*(4), 283-300.

Cushman, J. G., Laidler, A., Russell, D. G., Wilson, N. C., & Herbison, G. P. (1991). *Life in New Zealand* (Vol. 4). Wellington: Hillary Commission for Recreation and Sport.

Davis, J. B., Guillemain, M., Kaminski, R. M., Arzel, C., Eadie, J. M., & Rees, E. C. (2014). Habitat and resource use by waterfowl in the northern hemisphere in autum and winter. *Wildfowl*(4), 17-69.

Dawson, R. D., & Clark, R. G. (2000). Effects of hatching date and egg size on growth, recruitment, and adult size of lesser scaup. *The Condor, 102*(4), 930-935.

Devries, J. H., Brook, R. W., Howerter, D. W., & Anderson, M. G. (2008). Effects of spring body condition and age on reproduction in mallards (Anas platyrhynchos). *The Auk, 125*(3), 618-628.

Devries, J. H., Citta, J. J., Lindberg, M. S., Howerter, D. W., & Anderson, M. G. (2003). Breeding-season survival of mallard females in the Prairie Pothole Region of Canada. *The Journal of Wildlife Management, 67*(3), 551-563.

Dietz, N. J., Bergmann, P. J., & Flake, L. D. (1994). A walk-in trap for nesting ducks. *Wildlife Society Bulletin, 22*(1), 19-22.

Dinsmore, S. J., White, G. C., & Knopf, F. L. (2002). Advanced techniques for modeling avian nest survival. *Ecology, 82*(12), 3476-3488.

Duebbert, H. F., & Frank, A. M. (1984). Value of prairie wetlands to duck broods. *Wildlife Society Bulletin, 12*(1), 27-34.

Duncan, R. P., Blackburn, T. M., & Worthy, T. H. (2002). Prehistoric bird extinctions and human hunting. *Proc Biol Sci, 269*(1490), 517-521.

Dunlap, T. R. (1999). *Nature and the English Diaspora: Environment and History in the United States, Canada, Australia, and New Zealand*. U.S.A: Cambridge University Press.

Dyer, J., & Williams, M. (2010). An introduction most determined: Mallard *(Anas platyrhynchos)* to New Zealand. *Notornis, 57*, 178-195.

Dzus, E. H., & Clark, R. G. (1997a). Brood size manipulation in mallard ducks: Effects on duckling survival and brooding efficiency. *Ecoscience, 4*(4), 437-445.

Dzus, E. H., & Clark, R. G. (1997b). Overland travel, food abundance, and wetland use by mallards: relationships with offspring survival. *The Wilson Bulletin, 109*(3), 504-515.

Dzus, E. H., & Clark, R. G. (1998). Brood survival and recruitment of mallards in relation to wetland density and hatching date. *The Auk, 115*(2), 311-318.

Eadie, J. M., Kehoe, F. P., & Nudds, T. D. (1988). Pre-hatch and post-hatch brood amalgamation in North American Anatidae: a review of hypotheses. *Canadian Journal of Zoology, 66*(8), 1709-1721.

Eichholz, M. W., & Elmberg, J. (2014). Nest site selection by Holarctic waterfowl: a multi-level review. *Wildfowl*(4), 86-130.

Euliss Jr., N. H., Wrubleski, D. A., & Mushet, D. M. (1999). Wetlands of the Prairie Pothole Region: invertebrate species composition, ecology, and management. In D. P. Batzer, R. B. Rader, & S. A. Wissinger (Eds.), *Invertebrates in freshwater wetlands of North America: ecology and management.* (pp. 471-514). New York, USA: John Wiley and Sons.

Fraser, K. W. (2000). *Status and conservation role of recreational hunting on conservation land*. Wellington: Department of Conservation.

Garrettson, P. R., & Rohwer, F. C. (2001). Effects of mammalian predator removal on production of upland-nesting ducks in North Dakota. *The Journal of Wildlife Management, 65*(3), 398-405.

Gendron, M., & Clark, R. G. (2002). Survival of gadwall and mallard ducklings in Southcentral Saskatchewan. *The Journal of Wildlife Management, 66*(1), 170-180.

Gilsdorf, J. M., Vercauteren, K. C., Hygnstrom, S. E., Walter, W. D., Boner, J. R., & Clements, G. M. (2008). An integrated vehicle-mounted telemetry system for VHF telemetry applications. *The Journal of Wildlife Management, 72*(5), 1241-1246.

Gjersing, F. M. (1975). Waterfowl production in relation to rest-rotation grazing. *Journal of Range Management, 28*(1), 37-42.

Gloutney, M. L., & Clark, R. G. (1997). Nest-site selection by mallards and blue-winged teal in relation to microclimate. *The Auk, 114*(3), 381-395.

Greenwood, R. J., Sargeant, A. B., Johnson, D. H., Cowardin, L. M., & Shaffer, T. L. (1995). Factors associated with duck nest success in the Prairie Pothole Region of Canada. *Wildlife Monographs* 128, 3-57.

Grueber, C. E., Nakagawa, S., Laws, R. J., & Jamieson, I. G. (2011). Multimodel inference in ecology and evolution: challenges and solutions. *Journal of Evolultionary Biology, 24*(4), 699-711.

Gunnarsson, G., Elmberg, J., Sjoberg, K., Poysa, H., & Nummi, P. (2006). Experimental evidence for density-dependent survival in mallard *(Anas platyrhynchos)* ducklings. *Oecologia, 149*, 203-213.

Hanson, H. C. (1949). Methods of determining age in canada geese and other waterfowl. *The Journal of Wildlife Management, 13*(2), 177-183.

Hoekman, S. T., Gabor, T. S., Maher, R., Murkin, H. R., & Armstrong, L. M. (2004). Factors affecting survival of mallard ducklings in Southern Ontario. *The Condor, 106*(3), 485-495.

Hoekman, S. T., Mills, L. S., Howerter, D. W., Devries, J. H., & Ball, I. J. (2002). Sensitivity analyses of the life cycle of Midcontinent mallards. *The Journal of Wildlife Management, 66*(3), 883-900.

Holechek, J. L., Valdez, R., Schemnitz, S. D., Pieper, R. D., & Davis, C. A. (1982). Manipulation of grazing to improve or maintain wildlife habitat. *Wildlife Society Bulletin, 10*(3), 204-210

Hopper, R. M., & Funk, H. D. (1970). Reliability of the mallard wing age-determination technique for field use. *The Journal of Wildlife Management, 34*(2), 333-339.

Hormay, A. L., & Talbot, M. W. (1961). *Rest-rotation grazing. A new management system for perennial bunchgrass ranges* (Vol. 51): U.S Department of Agriculture.

Horn, D. J., Phillips, M. L., Koford, R. R., Clark, W. R., Sovada, M. A., & Greenwood, R. J. (2005). Landscape composition, patch size, and distance to edges: Interactions affecting duck reproductive success. *Ecological Applications, 15*(4), 1367-1376.

Howerter, D. W., Anderson, M. G., Devries, J. H., Joynt, B. L., Armstrong, L. M., Emery, R. B., & Arnold, T. W. (2014). Variation in mallard vital rates in Canadian Aspen Parklands: The Prairie Habitat Joint Venture assessment. *Wildlife Monographs, 188*(1), 1-37.

Howerter, D. W., Rotella, J. J., Anderson, M. G., Armstrong, L. M., & Devries, J. H. (2008). Mallard nest-site selection in an altered environment: Predictions and patterns. *Israel Journal of Ecology & Evolution, 54*(3-4), 435-457.

Hoyt, D. F. (1979). Practical methods of estimating volume and fresh weight of bird eggs. *The Auk, 96*(1), 73-77.

Jewell, P. A., & Holt, S. (1981). *Problems in Management of Locally Abundant Wild Mammals*. New York, U.S.A: Academic Press, Inc.

Johnson, D. H. (1980). The comparison of usage and availability measurements for evaluating resource preference *Ecology, 61*(1), 65-71.

Johnson, D. H., Nichols, J. D., & Schwartz, M. D. (1992). Population dynamics of breeding waterfowl. In B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, & G. L. Krapu (Eds.), *Ecology and management of breeding waterfowl* (pp. 447-485). Minneapolis, MN: University of Minnesota Press.

Jones, J. (2001). Habitat selection studies in avian ecology: A critical review. *The Auk, 118*(2), 557.

Kadlec, J. A., & Smith, L. M. (1992). Habitat management for breeding areas. In B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, & G. L. Krapu (Eds.), *Ecology and management of breeding waterfowl* (pp. 590-610). Minneapolis, MN, USA: University of Minnesota Press.

Kaminski, M. R., Baldassarre, G. A., Davis, J. B., Wengert, E. R., & Kaminski, R. M. (2013). Mallard survival and nesting ecology in the Lower Great Lakes Region, New York. *Wildlife Society Bulletin, 37*(4), 778-786.

Kaminski, R. M., & Elmberg, J. (2014). An introduction to habitat use and selection by waterfowl in the northern hemisphere. *Wildfowl*(4), 9-16.

Klett, A. T., Duebbert, H. F., Faanes, C. A., & Higgins, K. F. (1986). *Techniques for studying nest success of ducks in upland habitats in the Prairie Pothole Region*. Washington, D.C, USA.

Klett, A. T., Shaffer, T. L., & Johnson, D. H. (1988). Duck nest success in the Prairie Pothole Region. *The Journal of Wildlife Management, 52*(3), 431-440.

Korschgen, C. E., & Dahlgren, R. B. (1992). *Human disturbances of waterfowl: causes, effects, and management*. Washington, D.C, USA: US Fish & Wildlife Service.

Krapu, G. L. (1981). The role of nutrient reserves in mallard reproduction. *The Auk, 98*(1), 29-38.

Krapu, G. L., Greenwood, R. J., Dwyer, C. P., Kraft, K. M., & Cowardin, L. M. (1997). Wetland use, settling patterns, and recruitment in mallards. *The Journal of Wildlife Management, 61*(3), 767-746.

Krapu, G. L., Johnson, D. H., & Dane, C. W. (1979). Age determination of mallards. *The Journal of Wildlife Management, 43*(2), 384-393.

Krapu, G. L., Pietz, P. J., Brandt, D. A., & Cox Jr., R. R. (2006). Mallard brood movements, wetland use, and duckling survival during and following a prairie drought. *The Journal of Wildlife Management, 70*(5), 1436-1444.

Krapu, G. L., Pietz, P. J., Brandt, D. A., & Cox, R. R., Jr. (2000). Factors limiting mallard brood survival in Prairie Pothole landscapes. *The Journal of Wildlife Management, 64*(2), 553-561.

Krapu, G. L., Pietz, P. J., Brandt, D. A., Cox, R. R., & Sheaffer. (2004). Does presence of permanent fresh water affect recruitment in prairie-nesting dabbling ducks? *Journal of Wildlife Management, 68*(2), 332-341.

Krapu, G. L., & Reinecke, K. J. (1992). Foraging ecology and nutrition. In B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, & G. L. Krapu (Eds.), *Ecology and management of breeding waterfowl* (pp. 1-29). Minneapolis, MN, USA: University of Minnesota Press.

Langham, N. P. E. (1991). Feral cats (*Felis catus* L.). *Wildlife Research, 18*, 741-760.

Lele, S. R., Merrill, E. H., Keim, J., & Boyce, M. S. (2013). Selection, use, choice and occupancy: Clarifying concepts in resource selection studies. *J Anim Ecol, 82*(6), 1183-1191.

M.P.I. (2013). *The dairying and clean streams accord: snapshot of progress 2011/2012*. Wellington, NZ: Ministry for Primary Industries Retrieved from https://www.mpi.govt.nz/document-vault/4249.

Mack, G. G., & Clark, R. G. (2006). Home-range characteristics, age, body size, and breeding performance of female mallards *(Anas platyrhynchos)*. *The Auk, 123*(2), 467-474.

MacLeod, C. J., & Moller, H. (2006). Intensification and diversification of New Zealand agriculture since 1960: An evaluation of current indicators of land use change. *Agriculture, Ecosystems & Environment, 115*(1–4), 201-218.

Manly, B. F. J., McDonald, L. L., Thomas, D. L., McDonald, T. L., & Erickson, W. P. (2002). *Resource selection by animals: statistical design and analysis for field studies* (Second ed.): Springer Netherlands.

Martin, C. J. (2009). *Compensatory predation on ducks in a complex prairie food web.* University of Guelph, Ontario, Canada.

Martin, T. E. (1998). Are microhabitat preferences of coexisting species under selection and adaptive? *Ecology, 79*(2), 656-670.

Mauser, D. M., & Jarvis, R. L. (1991). Attaching radio transmitters to 1-day-old mallard ducklings. *The Journal of Wildlife Management, 55*(3), 488-491.

Mauser, D. M., Jarvis, R. L., & Gilmer, D. S. (1994). Movements and habitat use of mallard broods in Northeastern California. *The Journal of Wildlife Management, 58*(1), 88-94.

Mayr, E. (1970). *Populations, species and evolution*. Massachusetts, USA: Harvard University Press.

McDowall, R. M. (1994). *Gamekeepers for the nation: the story of New Zealand's acclimatisation societies, 1861-1990*: Canterbury University Press.

McRoberts, J. T., Quintana, N. T., Smith, W. A., Ballard, W. B., Kehoe, F. P., & Dilworth, T. G. (2012). Greater Scaup *Aythya marila*, nest site characteristics on Grassy Island, New Brunswick. *Canadian Field-Naturalist, 126*(1), 15-19.

Michel, P., Dickinson, K. J. M., Barratt, B. I. P., & Jamieson, I. G. (2010). Habitat selection in reintroduced bird populations: a case study of Stewart Island robins and South Island saddlebacks on Ulva Island. *New Zealand Journal of Ecology, 34*(2), 237-246.

Mundinger, J. G. (1976). Waterfowl response to rest-rotation grazing. *The Journal of Wildlife Management, 40*(1), 60-68.

Nakagawa, S., & Freckleton, R. P. (2011). Model averaging, missing data and multiple imputation: a case study for behavioural ecology. *Behavioral Ecology and Sociobiology, 65*(1), 103-116.

Nugent, G. (1992). Big-game, small-game, and gamebird hunting in New Zealand: Hunting effort, harvest, and expenditure in 1988. *New Zealand Journal of Zoology, 19*(3-4), 75-90.

Olsen, G. H., Dein, F. J., Haramis, G. M., & Jorde, D. G. (1992). Implanting radio transmitters in wintering canvasbacks. *The Journal of Wildlife Management, 56*(2), 325-328.

Orthmeyer, D. L., & Ball, I. J. (1990). Survival of mallard broods on Benton Lake National Wildlife Refuge in Northcentral Montana. *The Journal of Wildlife Management, 54*(1), 62-66.

Paquette, G. A., Devries, J. H., Emery, R. B., Howerter, D. W., Joynt, B. L., & Sankowski, T. P. (1997). Effects of transmitters on reproduction and survival of wild mallards. *The Journal of Wildlife Management, 61*(3), 953-961.

Pearse, A. T., Johnson, D. H., Richkus, K. D., Rohwer, F. C., Cox, R. R., & Padding, P. I. (2014). Accuracy of aging ducks in the U.S. Fish and Wildlife Service Waterfowl Parts Collection Survey. *Wildlife Society Bulletin, 38*(1), 26-32.

Pearse, A. T., & Ratti, J. T. (2004). Effects of predator removal on mallard duckling survival. *Journal of Wildlife Management, 68*(2), 342-350.

Pietz, P. J., Brandt, D. A., Krapu, G. L., & Buhl, D. A. (1995). Modified transmitter attachment method for adult ducks. *Journal of Field Ornithology, 66*(3), 408-417.

Pietz, P. J., Krapu, G. L., Brandt, D. A., & Cox, R. R., Jr. (2003). Factors affecting gadwall brood and duckling survival in prairie pothole landscapes. *The Journal of Wildlife Management, 67*(3), 564-575.

Poysa, H. (2001). Dynamics of habitat distribution in breeding mallards: assessing the applicability of current habitat selection models. *Oikos, 94*(2), 365-373.

Poysa, H., Milonoff, M., Ruusila, V., & Virtanen, J. (1999). Nest-site selection in relation to habitat edge: experiments in the Common Goldeneye. *Journal of Avian Biology, 30*(1), 79-84.

R Core Development Team (Version 3.2.0). (2013). http://www.r-project.org/.

Ragg, J. R., & Moller, H. (2000). Microhabitat selection by feral ferrets *(Mustela furo)* in a pastoral habitat, East Otago, New Zealand. *New Zealand Journal of Ecology, 24*(1), 39-46.

Rhymer, J. M. (1992). An experimental study of geographic variation in avian growth and development. *Journal of Evolutionary Biology, 5*, 289-306.

Rhymer, J. M., Williams, M. J., & Braun, M. J. (1994). Mitochondrial analysis of gene flow between New Zealand mallards *(Anas platyrhynchos)* and grey ducks *(A. superciliosa)*. *The Auk, 111*(4), 970-978.

Rotella, J. J., Clark, R. G., & Afton, A. D. (2003). Survival of female Lesser Scaup: Effects of body size, age, and reproductive effort. *The Condor, 105*(2), 336-347.

Rotella, J. J., Dinsmore, S. J., & Shaffer, T. L. (2004). Modeling nest-survival data: a comparison of recently developed methods that can be implemented in MARK and SAS. *Animal Biodiversity and Conservation, 27*(1), 187-205.

Rotella, J. J., Howerter, D. W., Sankowski, T. P., & Devries, J. H. (1993). Nesting effort by wild mallards with 3 types of radio transmitters *The Journal of Wildlife Management, 57*(4), 690-695.

Rotella, J. J., & Ratti, J. T. (1990). Use of methoxyflurane to reduce nest abandonment of mallards. Journal of Wildlife Management 54:627-628.

Rotella, J. J., & Ratti, J. T. (1992). Mallard brood survival and wetland habitat conditions in Southwestern Manitoba. *The Journal of Wildlife Management, 56*(3), 499-507.

Sargeant, A. B., & Raveling, D. G. (1992). Mortality during the breeding season. In B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, & G. L. Krapu (Eds.), *Ecology and management of breeding waterfowl* (pp. 396-422). Minneapolis, MN, USA: University of Minnesota Press.

Schick, R. S., Loarie, S. R., Colchero, F., Best, B. D., Boustany, A., Conde, D. A., . . . Clark, J. S. (2008). Understanding movement data and movement processes: current and emerging directions. *Ecol Lett, 11*(12), 1338-1350.

Schielzeth, H. (2010). Simple means to improve the interpretability of regression coefficients. *Methods in Ecology and Evolution, 1*(2), 103-113.

Sedinger, J. S. (1992). Ecology of prefledging waterfowl. In B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, & G. L. Krapu (Eds.), *Ecology and Management of Breeding Waterfowl* (pp. 109-127). Minneapolis, USA: University Minnesota Press.

Sharp, R., & Wollscheid, K.-U. (2009). Recreational hunting, conservation and rural livelihoods. Conservation science and practice. In B. Dickson, J. Hutton, & W. M. Adams (Eds.), (1 ed., Vol. 4). UK: Blackwell Publishing Ltd.

Simpson, J. W., Yerkes, T., Nudds, T. D., & Smith, B. D. (2007). Effects of habitat on mallard duckling survival in the Great Lakes Region. *The Journal of Wildlife Management, 71*(6), 1885-1891.

Sinclair, A. R. E., Fryxell, J. M., & Caughley, G. (2006). *Wildlife ecology, conservation, and management* (Second ed.): Blackwell Publishing.

Sovada, M. A., Zicus, M. C., Greenwood, R. J., Rave, D. P., Newton, W. E., Woodward, R. O., & Beiser, J. A. (2000). Relationships of habitat patch size to predator community and survival of duck nests. *The Journal of Wildlife Management, 64*(3), 820-831.

Stephens, S. E., Koons, D. N., Rotella, J. J., & Willey, J. J. (2003). Effects of habitat fragmentation on avian nesting success: a review of the evidence at multiple spatial scales. *Biological Conservation, 115*(1), 101-110.

Stephens, S. E., Rotella, J. J., Lindberg, M. S., Taper, M. L., & Ringelman, J. K. (2005). Duck nest survival in the Missouri coteau of North Dakota: landscape effects at multiple spatial scales. *Ecological Applications, 15*(6), 2137-2149.

Street, M. (1978). The role of insects in the diet of mallard ducklings - an experimental approach. *Wildfowl, 29*, 93-100.

Swanson, G. A., Meyer, M. I., & Adomaitis, V. A. (1985). Foods consumed by breeding mallards on wetlands of South -Central North Dakota. *The Journal of Wildlife Management, 49*(1), 197-203.

Symonds, M. R. E., & Moussalli, A. (2011). A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. *Behavioral Ecology and Sociobiology, 65*(1), 13-21.

Talent, L. G., Jarvis, R. L., & Krapu, G. L. (1983). Survival of mallard broods in South-Central North Dakota. *The Condor, 85*(1), 74-78.

Talent, L. G., Krapu, G. L., & Jarvis, R. L. (1982). Habitat use by mallard broods in south central North Dakota. *The Journal of Wildlife Management, 46*(3), 629-635.

Thompson, S. J., Arnold, T. W., & Vacek, S. (2012). Impact of encroaching woody vegetation on nest success of upland nesting waterfowl. *The Journal of Wildlife Management, 76*(8), 1635-1642.

Thorington, K. K., & Bowman, R. (2003). Predation rate on artificial nests increases with human housing density in suburban habitats. *Ecography, 26*, 188-196.

Tidwell, P. R., Webb, E. B., Vrtiska, M. P., & Bishop, A. A. (2013). Diets and food selection of female mallards and blue-winged teal during spring migration. *Journal of Fish and Wildlife Management, 4*(1), 63-74.

Walker, J., Rotella, J. J., Schmidt, J. H., Loesch, C. R., Reynolds, R. E., Lindberg, M. S., . . . Stephens, S. E. (2013a). Distribution of duck broods relative to habitat characteristics in the Prairie Pothole Region. *The Journal of Wildlife Management, 77*(2), 392-404.

Walker, J., Rotella, J. J., Stephens, S. E., Lindberg, M. S., Ringelman, J. K., Hunter, C., & Smith, A. J. (2013b). Time-lagged variation in pond density and primary productivity affects duck nest survival in the Prairie Pothole Region. *Ecological Applications, 23*(5), 1061-1074.

Warren, J. M., Rotella, J., & Thompson, J. E. (2008). Contrasting effects of cattle grazing intensity on upland-nesting duck production at nest and field scales in the Aspen Parkland, Canada. *Avian Conservation and Ecology, 3*(2), 6.

Weller, M. W. (1956). A simple field candler for waterfowl eggs. *The Journal of Wildlife Management, 20*(2), 111-113.

Weller, M. W. (1957). An automatic nest-trap for waterfowl. *The Journal of Wildlife Management, 21*(4), 456-458.

White, G. C. (2015). Program MARK: Mark and recapture parameter estimation (Version 8.0). Fort Collins, CO, USA: http://www.phidot.org/software/mark/.

Williams, M. J. (1981). *The Duckshooter's Bag*. Wellington, New Zealand: The Wetland Press.

Williams, M. J., & Basse, B. (2006). Indigenous gray ducks *Anas superciliosa*, and introduced mallards, *A. platyrhynchos*, in New Zealand: processes and outcome of a deliberate encounter. *Acta Zoologica Sinica, 52*(Supplement), 579-582.

Yerkes, T. (2000). Influence of female age and body mass on brood and duckling survival, number of surviving ducklings, and brood movements in Redheads. *The Condor, 102*(4), 926-929.

Appendices

Appendix A

Table A2.3: Percentage habitat composition summarised within the total study area (30km^2), within each female's 50 m radius used-route buffer created using a straight line trajectory between observed locations, and by the distribution of each female's radio location point data for mallards in Southland, New Zealand, 2014.

	% habitat in used route buffer			**% radio locations**		
Female ID	**Dense cover**	**Sheep**	**Dairy**	**Dense cover**	**Sheep**	**Dairy**
1	3.07	91.92	0.00	71.43	28.57	0.00
2	5.40	9.47	77.32	84.62	0.00	15.38
3	6.31	0.88	82.28	63.64	27.27	9.09
4	20.71	62.23	0.00	75.00	25.00	0.00
5	8.83	86.51	0.00	81.25	18.75	0.00
6	9.86	17.72	64.45	73.33	0.00	26.67
7	6.88	1.14	80.51	73.33	0.00	26.67
8	19.48	69.36	6.75	73.33	26.67	0.00
9	25.75	40.47	0.00	100.00	0.00	0.00
10	5.93	0.00	87.11	33.33	0.00	66.67
11	17.85	53.85	7.23	100.00	0.00	0.00
12	11.34	39.13	27.19	86.67	13.33	0.00
13	9.02	82.09	0.00	73.33	26.67	0.00
14	7.44	8.40	83.54	73.33	0.00	26.67
15	20.20	20.69	58.62	100.00	0.00	0.00
16	23.82	16.67	53.61	93.75	6.25	0.00
17	13.35	16.69	64.03	36.36	27.27	36.36
18	9.95	29.71	20.47	66.67	16.67	16.67

	% habitat in used route buffer			% radio locations		
Female ID	**Dense cover**	**Sheep**	**Dairy**	**Dense cover**	**Sheep**	**Dairy**
19	8.00	84.36	0.00	86.67	13.33	0.00
20	8.55	52.17	0.00	100.00	0.00	0.00
21	29.23	68.84	0.00	75.00	25.00	0.00
22	25.49	70.01	0.00	61.54	38.46	0.00
23	5.70	86.73	0.00	40.00	60.00	0.00
24	6.62	65.41	15.24	86.67	13.33	0.00
25	7.89	3.20	85.60	100.00	0.00	0.00
26	35.40	60.58	0.00	100.00	0.00	0.00
27	4.59	86.14	0.00	37.50	62.50	0.00
28	8.07	80.16	0.00	100.00	0.00	0.00
29	9.42	5.71	82.00	66.67	0.00	33.33
30	9.82	82.79	0.47	46.67	53.33	0.00
31	14.60	19.19	59.11	100.00	0.00	0.00
32	16.90	1.22	76.51	66.67	0.00	33.33
33	6.78	4.30	74.38	46.67	0.00	53.33
34	6.35	1.21	87.62	75.00	0.00	25.00
35	22.87	66.85	4.86	66.67	33.33	0.00
36	9.70	11.15	57.33	30.00	0.00	70.00
37	12.48	41.18	27.22	44.44	11.11	44.44
38	5.26	25.75	61.38	14.29	14.29	71.43
39	20.93	1.92	71.61	75.00	0.00	25.00
40	9.98	0.00	74.98	61.54	0.00	38.46

	% habitat in used route buffer			% radio locations		
Female ID	**Dense cover**	**Sheep**	**Dairy**	**Dense cover**	**Sheep**	**Dairy**
41	12.62	0.08	77.92	66.67	0.00	33.33
42	9.29	0.00	82.98	100.00	0.00	0.00
43	2.26	0.00	89.74	41.67	0.00	58.33
44	2.80	0.00	83.44	53.85	0.00	46.15
45	8.35	84.02	0.00	61.54	38.46	0.00
46	6.73	4.88	78.38	81.82	0.00	18.18
47	24.71	0.00	67.39	100.00	0.00	0.00
% of study area	8.95	45.67	45.37			

Table A2.4: A summary of mean, minimum and maximum values for continuous covariates observed for mallard duckling broods in Southland, New Zealand, 2014.

Covariates[a]	**Mean**	**Minimum**	**Maximum**
PercNat (%)	13.19	0	50.07
Dmoved (m)	118.43	1.41	963.03
Dhouse (m)	234.5	56.6	490.00
Esize (mL)	56.80	45.68	67.88
Bsize (nest exodus)	9.06	5	15
Dwater (m)	59.73	0	564.58
Precip (mL)	3.51	0	23

[a] PercNat = percentage of dense nesting cover within a females’ 50 m used-route buffer, Dmoved = average distance brood moved per day, Dhouse = average distance of brood locations from anthropogenic structures (buildings and roads), Esize = average egg volume within a clutch, Bsize = number of ducklings that successfully left the nest bowl, Dwater = average distance of brood locations from sources of permanent water (ponds, streams and ditches) and Precip = average weighted precipitation over the first ten days of life

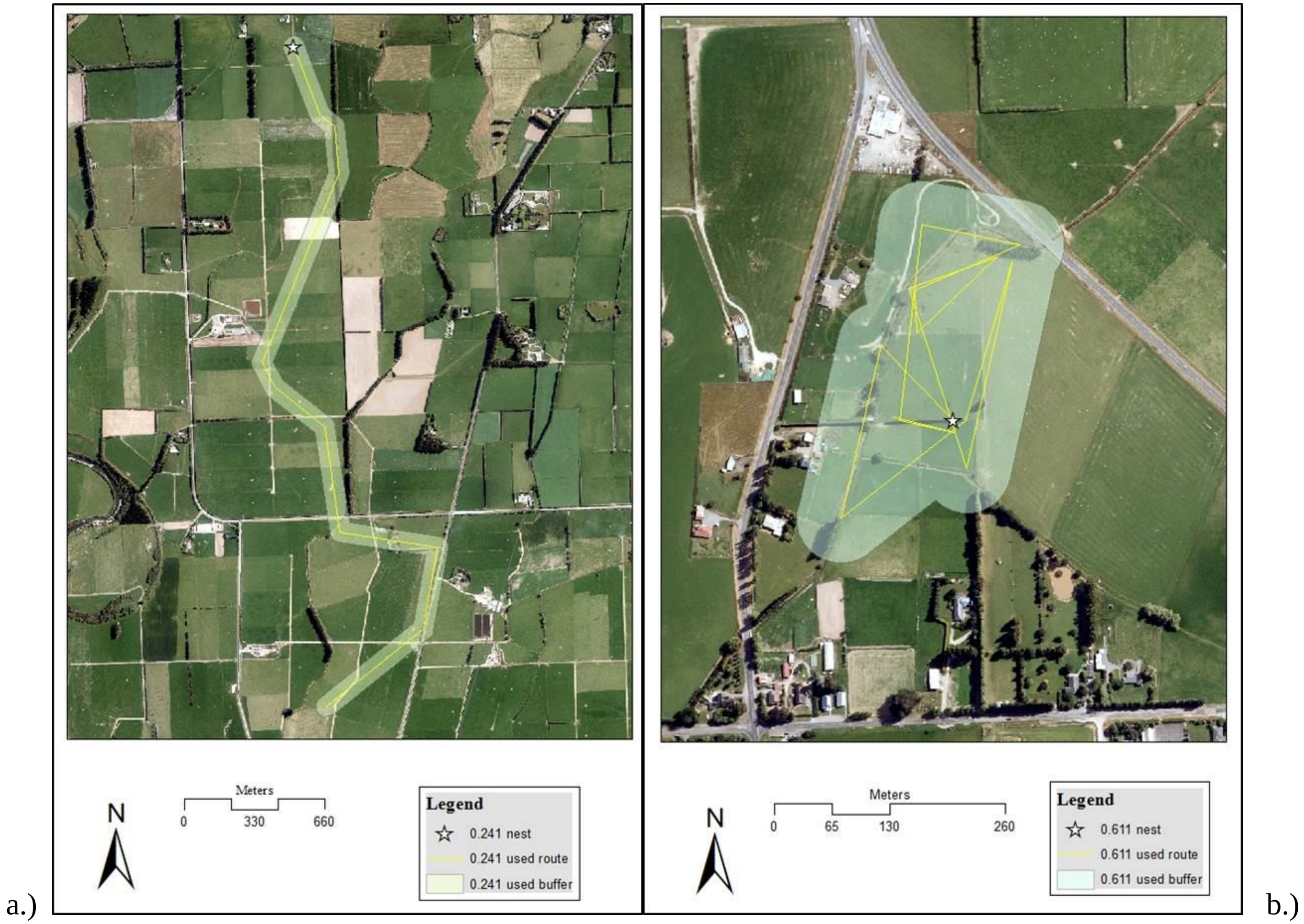

Figure A2.6: Visual representation of differing tendencies for overland movement between (a) female 0.241 (unsuccessfully raised a brood) and (b) female 0.611 (successfully fledged two ducklings) in Southland, New Zealand, 2014. The white star represents each females' nest site, yellow lines represent the brood route, and the blue area represents a 50 m buffer.

Table A2.5: A representative subset (the 24 models < 2.0 $QAIC_c$ units from the most supported model) of the 1024 model combinations analysed on duckling survival in Southland, New Zealand, 2014.

Model[a]	**$QAIC_c$**	**Δ $QAIC_c$**	**AIC_c Weights**	**Model Likelihood**	**# Parameters**	**QDeviance**
{INT+LOGAGE+FAGE+YEPHEMERAL+DHOUSE+PERCNAT+DMOVED}	348.1336	0	0.01141	1.0001	7	334.1155
{INT+LOGAGE+FAGE+YEPHEMERAL+ESIZE+DHOUSE+PERCNAT+DMOVED}	348.2178	0.0842	0.01094	0.9589	8	332.1945
{INT+LOGAGE+FAGE+PERCNAT+DMOVED}	348.3222	0.1886	0.01038	0.9098	5	338.3125
{INT+LOGAGE+FAGE+YEPHEMERAL+PERCNAT+DMOVED}	348.4913	0.3577	0.00954	0.8362	6	336.4777
{INT+LOGAGE+FAGE+YEPHEMERAL+DATE+DHOUSE+PERCNAT+DMOVED}	348.7998	0.6662	0.00818	0.717	8	332.7764
{INT+LOGAGE+FAGE+YEPHEMERAL+ESIZE+PERCNAT+DMOVED}	349.132	0.9984	0.00693	0.6074	7	335.1139
{INT+LOGAGE+FAGE+YEPHEMERAL+BSIZE+DHOUSE+PERCNAT+DMOVED}	349.27	1.1364	0.00646	0.5662	8	333.2466
{INT+LOGAGE+FAGE+YEPHEMERAL+DATE+ESIZE+DHOUSE+PERCNAT+DMOVED}	349.3529	1.2193	0.0062	0.5434	9	331.3237
{INT+LOGAGE+FAGE+BSIZE+PERCNAT+DMOVED}	349.3699	1.2363	0.00615	0.5391	6	337.3562

{INT+LOGAGE+YEPHEMERAL+BSIZE+DHOUSE+PERCNAT+DMOVED}	349.6684	1.5348	0.0053	0.4646	7	335.6502
{INT+LOGAGE+FAGE+YEPHEMERAL+PRECIP+DHOUSE+PERCNAT+DMOVED}	349.6816	1.548	0.00526	0.4611	8	333.6582
{INT+LOGAGE+FAGE+ESIZE+PERCNAT+DMOVED}	349.7031	1.5695	0.00521	0.4567	6	337.6895
{INT+LOGAGE+FAGE+YEPHEMERAL+BSIZE+ESIZE+DHOUSE+PERCNAT+DMOVED}	349.7562	1.6226	0.00507	0.4444	9	331.727
{INT+LOGAGE+YEPHEMERAL+DHOUSE+PERCNAT+DMOVED}	349.7565	1.6229	0.00507	0.4444	6	337.7429
{INT+LOGAGE+FAGE+PERCNAT}	349.7757	1.6421	0.00502	0.44	4	341.7693
{INT+LOGAGE+FAGE+DHOUSE+PERCNAT+DMOVED}	349.811	1.6774	0.00493	0.4321	6	337.7974
{INT+LOGAGE+FAGE+YEPHEMERAL+DATE+PERCNAT+DMOVED}	349.8935	1.7599	0.00473	0.4146	7	335.8753
{INT+LOGAGE+FAGE+LONG+YEPHEMERAL+ESIZE+DHOUSE+PERCNAT+DMOVED}	349.9389	1.8053	0.00463	0.4058	9	331.9097
{INT+LOGAGE+FAGE+YEPHEMERAL+BSIZE+PERCNAT+DMOVED}	349.9422	1.8086	0.00462	0.405	7	335.9241
{INT+LOGAGE+FAGE+DATE+PERCNAT+DMOVED}	349.9527	1.8191	0.00459	0.4023	6	337.9391
{INT+LOGAGE+FAGE+YEPHEMERAL+ESIZE+DHOUSE+DWATER+PERCNAT+DMOVED}	350.0051	1.8715	0.00448	0.3927	9	331.9758

{INT+LOGAGE+FAGE+YEPHEMERAL+PERCNAT}	350.0399	1.9063	0.0044	0.3857	5	340.0302
{INT+LOGAGE+FAGE+LONG+YEPHEMERAL+DHOUSE+PERCNAT+DMOVED}	350.043	1.9094	0.00439	0.3848	8	334.0196
{INT+LOGAGE+FAGE+YEPHEMERAL+DHOUSE+DWATER+PERCNAT+DMOVED}	350.0584	1.9248	0.00436	0.3822	8	334.035

[a] The full model included all measured variables {Int + LogAge +Fage + Ephemeral + Dhouse + PercNat + Dmoved + Dwater + Date + Precip + Pasture + Esize + Bsize}. All combinations of the model were run using Program MARK and ranked according to their corresponding $QAIC_c$. LogAge = log-linear trend on duckling age, Fage = female age (second-year and after-second-year), Ephemeral = presence (or not) of ephemeral water in the brood route, Dhouse = average distance of brood locations from anthropogenic structures (buildings and roads), PercNat = percentage of dense nesting cover within a females 50 m used-route buffer, Dmoved = average distance brood moved per day, Dwater = average distance of brood locations from sources of permanent water (ponds, streams and ditches), Date = date of hatch, Precip = average weighted precipitation over the first ten days of life, Pasture = short or long category representing the majority pasture type a brood was raised on, Esize = average egg volume within a clutch and Bsize = number of ducklings that successfully left the nest bowl. Models also included a random effect identifying females.

Appendix B

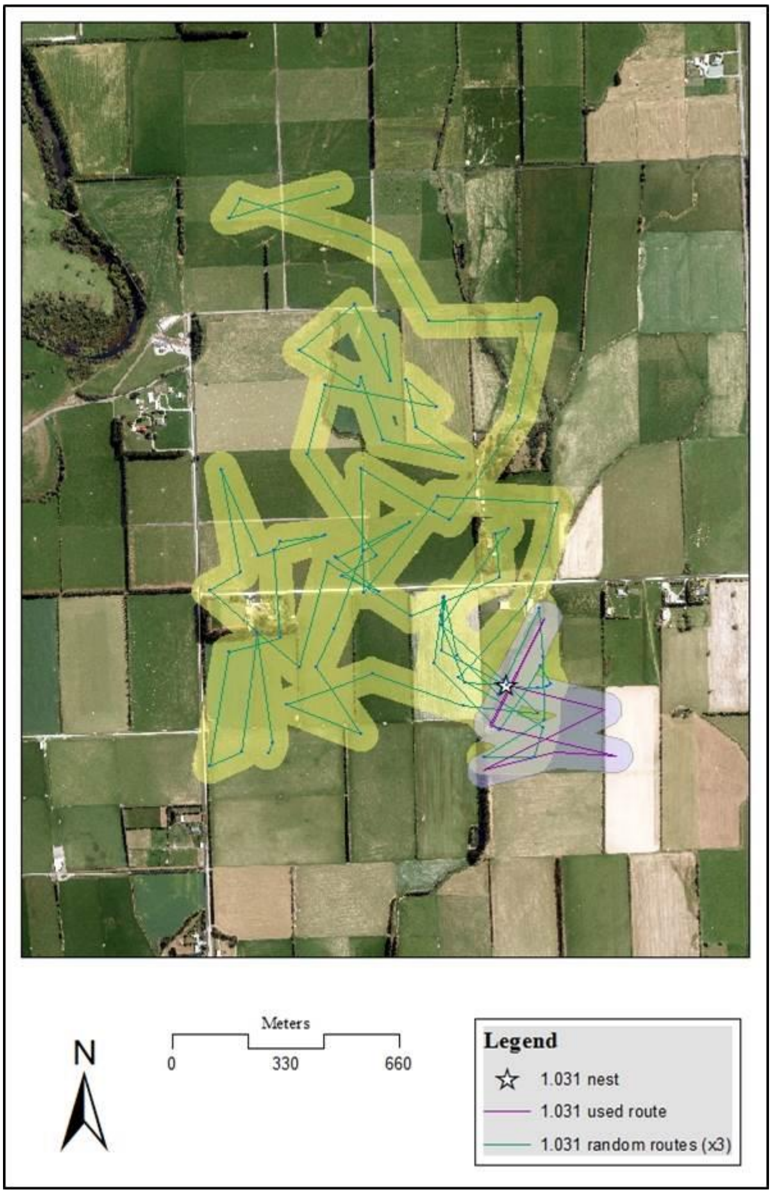

Figure B3.4: An example of a female’s used route (purple, with buffer) and her corresponding random available routes (yellow, with buffers) created from the Geospatial Modelling Environment (Beyer, 2012) in Southland, New Zealand 2014. As is evident, this female (frequency 1.031) did not move very far from her original nest site (star).

Table B3.4: The number of days alive and corresponding brood used-route areas for mallard females in Southland, New Zealand 2014.

Female ID	Used-route area (m^2)	Days Alive
1	187,638	7
2	273,132	30
3	108,775	10
4	146,253	30
5	57,894	30
6	156,450	30
7	94,185	30
8	126,267	30
9	21,271	8
10	406,433	20
11	141,572	25
12	101,713	30
13	91,708	30
14	143,512	30
15	57,910	30
16	193,001	29
17	145,484	10
18	170,153	26
19	91,018	30
20	11,154	8
21	100,454	12
22	63,080	15
23	154,775	30
24	238,868	29
25	117,025	30
26	21,850	1
27	136,638	30
28	105,877	3
29	276,926	30
30	84,311	30

31	61,325	1
32	212,620	30
33	251,375	30
34	255,500	30
35	174,828	15
36	106,281	15
37	122,573	8
38	395,540	30
39	31,954	6
40	180,392	30
41	206,613	30
42	78,815	3
43	92,366	15
44	85,350	25
45	169,274	30
46	134,385	30
47	12,870	6

Table B3.5: Model selection results for a generalized mixed model resource selection function of mallard brood habitat use in Southland, New Zealand 2014. Results include model definitions, ΔAIC_c, AIC_c weight (*w*), and adjusted R^2 for seven models with some support (i.e., $\Delta AIC_c < 2$ and $w > 0.05$). Danthro = average distance of brood locations from anthropogenic structures (buildings and roads), dDNC = average distance of brood locations from dense nesting cover, sheep = percent sheep pasture in brood route, dwater = average distance of brood locations from sources of permanent water, dairy = percent dairy pasture in brood route, brood fate = whether a female was successful in raising a brood to 30 days old ‘1’, or failed ‘0’. Models also included a random effect identifying ducklings within a brood.

Model[a]	ΔAIC_c[b]	*w*	Adjusted R^2
Int + dairy + danthro + dDNC + dDNC*brood fate	0.00	0.151	0.67
Int + dairy + danthro + dDNC + dwater + dDNC*brood fate	0.45	0.120	0.68
Int + dairy + danthro + dDNC + danthro*brood fate + dDNC*brood fate	0.68	0.104	0.74
Int + dairy + danthro + dDNC + dwater + danthro*brood fate + dDNC*brood fate	1.06	0.089	0.69
Int + dairy + dDNC + dDNC*brood fate	1.59	0.068	0.66
Int + dairy + dairy*brood fate + danthro + dDNC + dDNC*brood fate	1.72	0.064	0.68
Int + dairy + danthro + dDNC + dwater + dDNC*brood fate + dwater*brood fate	1.86	0.059	0.68

[a] The global model included variables of {Int + danthro + danthro*brood fate + dDNC + dDNC* brood fate + sheep + sheep* brood fate + dwater + dwater* brood fate + dairy + dairy* brood fate + brood_ID} with a strong negative correlation between sheep and dairy pastures, so these were only included in separate models as competing hypotheses.

[b] AIC_c value of most supported model was 109.9

Appendix C

Figure C4.1: Invertebrates (Class Oligochaeta) found in an ephemeral water body in Southland, New Zealand 2014.

Photo courtesy of Zane Moss 2014