Mallard duckling survival in response to brood habitat selection and use in Southland and Waikato

Prepared for: **New Zealand Fish and Game Council**
78 Victoria Street, Wellington 6011

Project: **Mallard brood habitat selection and use**

Jennifer L. Sheppard, PhD

62 Katerini Grove, Papamoa, 3118
Ph: 021 842 947
Email: jenn.sheppard14@gmail.com
August 2019

Document history and review

This report was reviewed internally and peer-reviewed by David Klee (Auckland/Waikato Fish and Game) and Matt McDougall (Eastern Fish and Game) as follows:

Version	Release Date	Reviewed by
Initial draft	1 June 2019	Simax Ecology internal review
V1 – Preliminary results	18 June 2019	M. McDougall (8 July)
V2 – Updated results and discussion	10 July 2019	D. Klee & M. McDougall (19 July)
V3 – Updated following peer-review feedback	24 July 2019	Simax Ecology internal review
V4 – Updated following internal review	28 July 2019	D. Klee (7 August; via email)
V5 – Updated management recommendations	12 August 2019	D. Klee (21 August)
V6 – Additional updates to management recommendations	20 August 2019	M. McDougall (21 August)
V7 – Incorporated edits from peer-review and finalised report	22 August 2019	D. Klee (23 August)
Final version	27 August 2019	—

Executive summary

Duckling survival is the most influential vital rate affecting population change of mallards (*Anas platyrhynchos*) in New Zealand. Understanding how habitat choices affect duckling survival can provide valuable insights for managing landscapes to increase productivity. Here, we evaluated habitat-selection of brood-rearing females at a spatial scale consistent with the brood-rearing habitat/home-range (200 m radius brood buffer) and evaluated whether habitat selection is adaptive (i.e., improves duckling survival) or maladaptive (e.g., decreases duckling survival or has no influence). We also assessed the use of smaller, local-scale habitats (within 5 m^2 of the brood) and investigated which characteristics were associated with higher duckling survival rates.

During 2014–2015, we conducted 2,252 observations of 190 brood-rearing female mallards on two study sites; one in Southland and one in Waikato. We used ArcGIS Pro to identify used and available habitats around brood travel routes and we used these data to predict duckling survival from interval-specific observation matrices of offspring counts and other covariates. We evaluated selection using generalized linear models and analyzed duckling survival data using a Bayesian hierarchical generalized linear model that simultaneously estimated daily duckling and brood survival, and individual duckling and brood detection. To further increase our understanding of local-scale habitats, we also related duckling survival to two different spatial scales of local habitat use: i) 'third-order habitat use' of the nearest waterbody, and ii) 'fourth-order habitat use' of the habitat where the brood was observed.

Habitat selection was strongest when drains, ponds, effluent ponds or sedge habitat constituted greater than 11%, 7%, 5%, or 13% of the brood buffer, respectively. Mallards that selected brood buffers with greater proportions of effluent ponds and streams experienced higher duckling survival, indicating adaptive selection. However, mallards also selected brood buffers with higher proportions of drains and ponds despite lower duckling survival associated with increased areas of these habitat types, suggesting these habitats may be ecological traps. Although we found no evidence of selection or avoidance of hedgerows, this habitat was associated with higher duckling survival, implying mallards may not always recognize beneficial habitats. Survival was also affected by water balance deficit such that daily duckling survival increased as soil moisture levels approached saturation.

Of the 2252 brood observations, 26% occurred in paddocks, 23% occurred in or near ponds, 18% occurred in streams, creeks or rivers, 17% occurred in drains, 7% occurred in effluent ponds and the remaining 9% occurred near roads or in fields. Duckling survival decreased when broods were closest to water and when there was taller vegetation within 5 m^2 of the brood observation, but was unaffected by habitat type, vegetation type, the percent of overhead cover or the percentage of emergent vegetation at the nearest waterbody.

Mallards exhibited both adaptive and maladaptive patterns of habitat selection of brood-rearing areas. Brood-rearing females tended to select areas with more drains, ponds, effluent ponds and to a lesser extent, streams. But at the brood-buffer scale only effluent

ponds conferred fitness benefits. These results suggest that (at the home-range scale) effluent ponds and streams may benefit ducklings while ponds and drains may act as ecological traps. Pronounced differences in waterbody characteristics, predator and invertebrate communities, and/or nutrient runoff and pollution may explain these results.

Given the importance of drains, streams, ponds and effluent ponds to duckling survival and habitat selection and use, additional research should be undertaken to evaluate predator and macroinvertebrate communities, and the chemical composition of each waterbody type. Such information could yield important insights into why ducklings survive better in certain waterbodies than others and may direct management actions in regards to predators, food sources, pollution and wetland vegetation.

In conclusion, we recommend that managers:

i)   Focus on increasing the area of sedge/rush habitat to attract birds to high quality wetlands (such as areas with lower predator numbers), while discouraging abundant planting of tall vegetation (i.e., some trees and shrubs might be okay, but too many seem to be detrimental).

ii)   Maintain hedgerows or promote planting of hedge species near important waterbodies.

iii)   Educate landowners about the importance of effluent ponds and encourage them to maintain riparian margins and fences. If landowners have lined ponds, then managers should also encourage wildlife escape mechanisms.

iv)   Maintain and enhance streams with dense ground cover vegetation (and hedge species).

v)   Direct efforts to prevent the removal of sub-surface drainage, especially during peak brood-rearing and promote the creation of seasonal or ephemeral wetlands.

vi)   Further investigate which characteristics of effluent ponds and streams promote duckling survival and whether these characteristics can be manipulated throughout other waterbodies to enhance duckling survival.

vii)   Continue to direct efforts to enhance habitat characteristics that have been linked to improved duckling survival or abundance, as determined from this study and associated studies throughout NZ. This includes increasing riparian margins, improving the quality of existing ponds and wetlands, identifying and conserving or creating wetlands where pest-fish have not established and promoting the creation and preservation of ephemeral wetlands.

viii)   Undertake initiatives to protect females during nesting and non-breeding seasons by protecting important nesting habitats or encouraging hunters to harvest fewer hens.

ix)   Conduct additional research to better understand predator and invertebrate communities of various habitat types so additional actions can be taken to improve these areas.

Acknowledgements

Table of Contents

List of Tables

List of Figures

INTRODUCTION

Duckling survival is the most influential factor affecting population growth of mallards (*Anas platyrhynchos*) in New Zealand (Sheppard 2018). Population models derived from data collected during 2014–2015 indicate a decreasing population ($\lambda = 0.84$; 95% CI $= 0.69$–1.03) but suggest that a 14% increase in cumulative duckling survival rates could lead to a stable population (Sheppard 2018). Low duckling survival may result from unproductive brood-rearing habitat, inadequate food sources or high predation rates and management of these factors may help promote duckling survival and ultimately result in population growth.

To date, research in New Zealand (NZ) has found that duckling survival increased with brood age and older females successfully raise more offspring, particularly in Southland (Garrick et al. 2017, Sheppard 2018). Data collected from 190 broods and 1780 ducklings during 2014–2015 suggested that brood and duckling survival were unaffected by year, as well as rainfall or temperature during brood-rearing (Sheppard 2018), while analysis of 438 ducklings from Southland in 2014 indicated that brood survival is unaffected by pasture type (dairy vs. sheep) but increased with the presence of ephemeral water and distance from anthropogenic structures (Garrick 2017). In the Bay of Plenty, McDougall et al. (2018) found that brood presence increased with drain width, the absence of drain maintenance and a greater extent of riparian grass and floating vegetation within the drain. However, researchers have yet to investigate several other exogenous factors that may affect duckling survival such as food availability, predation, predator abundance and habitat selection and use. Obtaining a better understanding of how any unexplored extrinsic factor may affect duckling survival will help guide management decisions in NZ.

During the "Mallard telemetry project" information on brood habitat use was collected but linking habitat-specific characteristics to duckling survival was outside the main scope of the PhD (Sheppard 2018) and MSc (Garrick 2015). Given the importance of duckling survival to population growth and the fact that this information has already been collected, a logical next step of the Mallard Research Program is to assess brood habitat use and selection. Relating duckling survival to habitat use and selection will provide valuable insights which may help increase duckling survival, and ultimately improve mallard productivity.

Here, we evaluated habitat selection of brood-rearing females at a spatial scale consistent with the brood-rearing habitat/home-range (200 m radius brood buffer) and evaluated whether habitat selection is adaptive (i.e., improves duckling survival) or maladaptive (e.g., decreases duckling survival or has no influence). We also assessed the use of smaller, local-scale habitats (within 5 m^2 of the brood) and investigated which characteristics of local-scale brood habitats are associated with higher duckling survival rates. We provide management recommendations on habitat improvement techniques and future research requirements

Habitat selection definitions and descriptions

This report investigates habitat selection and use, and focuses on identifying which habitats confer reproductive benefits. Additionally, we aim to identify any potential ecological or perceptual traps that may exist. Here, we provide definitions and descriptions of terms related to habitat selection so readers can better understand the results and outcomes of this project.

Adaptive habitat selection – occurs when organisms select and/or prefer habitats that increase fitness.

Brood-site selection – a result of second-order habitat selection. In this study, brood-site selection is determined by comparing habitats used by broods (brood buffer) to habitats that were not used by broods (random buffer).

Brood habitat use – akin to fourth-order habitat selection, but simply describes patterns of habitats used by broods. In this study, information on local-scale habitat use was collected during brood observations. For instance, we recorded the percent of overhead cover, the type of habitat the brood was in (i.e., pond vs. paddock), and the width of the riparian margin. While habitat selection cannot be inferred from this information, it can provide important information about habitat use patterns, which may aid conservation/management decisions.

Ecological trap – a type of evolutionary trap that occurs when an organism prefers/selects a habitat that is associated with lower fitness (i.e., the choice is maladaptive; Patten and Kelly 2010). For instance, insects may lay eggs on wet asphalt because reflection from nearby polarized lights create the appearance of favourable wetlands, but the water and eggs quickly dry up before eggs can hatch (Malik et al. 2010).

Evolutionary trap – in environments that have been anthropogenically modified or altered, or in new, novel environments, organisms make maladaptive behaviour or life-history choices based on formerly reliable environmental cues, despite the availability of higher quality options (Schalaepher et al. 2002).

Fitness – a vital rate measurement such as nest success or life-time reproductive success. In this study, we measure fitness as duckling survival.

Fitness/reproductive benefit – an increase in a measured vital rate in relation to a given habitat type. In this study, habitats that have reproductive benefits yield higher duckling survival.

Habitat – a piece of terrain large enough to meet all the resource requirements of an organism, enabling it to spend at least one breeding year there, and comprised of distinguishable habitat patches (or types) which differ from one another in ways that affect fitness (Orians 1980). In this study, habitat is the landscape/study area.

Habitat abundance – the quantity of a given habitat type in the environment (Johnson 1980). In this study, we measure habitat abundance by calculating the proportion of various habitat types within the brood buffers (the broods' home-range).

Habitat availability – the accessibility of a given habitat type to an organism (Johnson 1980). There are no lakes or orchards located throughout the Southland study area, so these habitat types are unavailable to broods there. Typically, if use exceeds availability, we have selection.

Habitat type – a distinguishable difference in habitat. In this study, we identify several habitat types (rank grass, woody cover, sedge) and use these in our evaluation of habitat selection.

Habitat preference – how organisms use their environment in relation to the habitats that are available; in accordance with the habitat selection theory, habitat preferences should be adaptive such that fitness is higher in preferred habitats and reliable environmental cues reflect habitat quality (Johnson 1980, Martin 1998). Habitats are preferred if use exceeds availability or avoided if availability exceeds use, thus preference is measured as the likelihood of a given habitat being chosen when offered on an equal basis with other habitat types (Johnson 1980). For instance, if there was only one lake in Southland (e.g., low availability) and a high number of broods used this lake (e.g., high use), then we would conclude that broods in Southland preferred and selected lakes.

Habitat selection – A hierarchical process that results from the disproportionate use of a given habitat type, and in theory, influences individual survival and fitness (Hutto 1985, Block and Brennan 1993); the process by which organisms actually chose a given habitat type (Johnson 1980). For instance, mallards might choose effluent ponds because they have more food resources for ducklings and through experience (or based on an environmental cue) they know that ducklings will be more likely to survive and grow faster in such habitats. As defined by Johnson (1980), there are four orders of selection:

i) First-order selection – the selection of the physical or geographical range of a species (i.e., the Waikato)
ii) Second-order selection – determines the home-range or core use-area of an individual (i.e., brood-rearing habitat or brood buffer)
iii) Third-order selection – pertains to the use of various habitat components within the home-range (i.e., ponds within the brood habitat, or a feeding site within the home range)
iv) Fourth-order selection – The procurement or use of items or habitats available at the site of selection (i.e., the use of a tree for cover at a pond within the brood area)

Habitat selection pattern – whether differences exist between used and available habitat (Clark and Shutler 1999).

Habitat selection process – whether and how successful and unsuccessful sites (in terms of fitness such as duckling survival) differ (Clark and Shutler 1999).

Habitat selection theory – suggests that animals should select habitats that optimize survival and reproductive success; if the process of habitat selection is adaptive, organisms should prefer higher quality habitats and avoid lower quality habitats (Levins 1968, Orians 1980).

Habitat selection trade-off – when birds select a habitat that benefits a given vital rate at the expense of a different vital rate. For instance, if roadsides are beneficial for nest survival but maladaptive for duckling survival because broods have to travel further to get to water (which decreases duckling survival), then there would be a trade-off between selecting nest-sites along roads.

Habitat use – refers to the way in which organisms use the environment to meet their life history needs such as the kind of food it consumes and the varieties of habitats it occupies; in other words, the quantity of a given habitat used by an organism (Johnson 1980).

Habitat use patterns – Describes the distribution of individuals across habitat types and are the end result of habitat selection processes (Hutto 1985, Jones 2001).

Perceptual trap – a type of evolutionary traps that occurs when organism avoid habitats that result in higher fitness (Patten and Kelly 2010). For instance, if lakes have a lot of food available such that ducklings would grow fast and all survive if they used lakes, but ducks avoid lakes because they are lined with willows or because they prefer an alternative habitat such as effluent ponds, then we have a perceptual trap.

METHODS

Field methods and brood observations

During 2014–2015, we captured 304 female mallards from study sites in Southland (46°12'S, 168°20'E) and Waikato (37°55'S, 175°18'E). In June or July of each year, 60 pre-breeding female per study area were equipped with a 22-g intra-abdominal radio-transmitter (Model IMP/150, Telonics, Mesa, Arizona, Sheppard et al. 2017). To monitor survival and to locate nests, we intensively tracked females using hand-held and truck-mounted radio-telemetry systems (Kenward 1987). From late August to early November, we located nests of unmarked mallards using a combination of techniques including beating vegetation with sticks during foot searches and using well-trained pointing dogs. We captured attending females on the nest during late incubation and equipped them with a 9-g back-mounted prong-and-suture radio-transmitter (Model LB-66, Telonics, Mesa, Arizona; Rotella et al. 1993, Paquette et al. 1997). Study sites, capture and marking procedures, and tracking regimes of pre-nesting and nesting birds are described in detail in Sheppard (2018). Due to the increased risk of mortality, ducklings were not equipped with transmitters or marked for future identification (Krapu et al. 2006, Amundson and Arnold 2010).

When we located nests, eggs were counted and candled to determine development stage (Weller 1956). We checked nests every 7–10 days until fate was determined and recorded the number of eggs during each visit. We passively checked nests using telemetry on the estimated day of hatch and every day thereafter until the female and ducklings left the nest (Sheppard 2018). We then approached the nest to confirm hatch and to count the remaining eggs and hatched membranes to determine initial brood size.

Following hatch, we tracked brood-rearing females every 1–3 days until the brood was 10 days of age, and then every 5–7 days thereafter until radio loss or failure occurred or the female: died; re-paired or flocked once ducklings were 45 days old or more; lost all the ducklings (e.g., complete brood mortality); or, successfully fledged at least 1 duckling (55–83 days post-hatch). Tracking abruptly ceased for 11 females that went missing before brood loss or a final count could be confirmed and for two broods that relocated to restricted land. During brood observations, we used binoculars or spotting scopes to obtain a full count of the surviving ducklings without disturbing the female and brood, but due to the secretive nature of broods and the landscape of the study areas, this was not always possible. At approximately 10, 30, 45, and 60 days of age, or whenever total brood failure was suspected, we used more invasive techniques (i.e., double observer methods, pushing/flushing broods towards hidden observers, closely approaching and flushing broods, or beat-outs) in an attempt to obtain full counts of the surviving ducklings. We classified brood observations as: i) full count, if investigator was confident in their count and could clearly see all ducklings present; ii) partial count, if investigator was uncertain of the count, the count was deemed incomplete, or the entire brood could not clearly be seen (i.e., visually blocked by vegetation, landscapes, or other structures); or, iii) mixed count, if ducklings were seen with more than one female and brood amalgamation was suspected, but separate counts of individual broods could not be obtained. Additional attempts were made to see the entire brood if a partial

count was suspected. If no sighting was obtained, the location of the female was estimated and 0 was logged as the count for ducklings, but observers made note of whether the female acted broody and if they suspected the brood was still alive or not.

During each brood observation, investigators recorded local-scale habitat information (within a 5 m^2 area of the brood) including the type of habitat the brood was in at the time of the observation (habitat type), the dominant vegetation type, the percent of overhead cover, and the height of the vegetation (Table 1 and Appendix 1). If the brood was near water, we also recorded the width of the riparian margin, the percent of emergent cover, the cover type of the waterbody, and whether the habitat was fenced. If the brood was also in a drain, we recorded the width, depth, type and shape of the drain (Table 1 and Appendix 1).

Table 1 – Description of local-scale habitat characteristics recorded during brood observations.

Habitat characteristics	Description
Collected for all observations	
Habitat type	A categorical variable describing the type of habitat the brood was in when first approached (not the habitat the brood was pushed into)
Vegetation type	A categorical variable describing the dominant type of vegetation within a 5 m^2 area of the brood when first observed
Vegetation height	The estimated maximum height (m; excluding outliers) of the vegetation within a 5 m^2 area of the brood
Overhead cover	The percent of mainly continuous layer of foliage above the brood (within 5 m^2)
Collected only if brood was near/in water	
Riparian width	The estimated width of the riparian margin (m), from the edge of the water to the edge of the bank
Emergent cover	The estimated percent of emergent vegetation (aquatic plants that are rooted to the bottom of the waterbody and have grown out of the water, providing vertical cover for broods) of a waterbody
Cover type	A categorical variable that refers to the percent and arrangement of emergent vegetation around the waterbody (Appendix 1)
Fenced	A categorical variable indicating whether the waterbody was fenced, and if so, if it was completely or partially fenced (i.e., one side of drain is fenced but other is not)
Collect only if brood was in drain/creek	
Drain width	The estimated width of the drain (from top of drain's riparian edge to other riparian edge).
Drain depth	The estimated depth of the drain, from top of drain to water level
Drain maintenance	A categorical variable indicating whether the drain is maintained (not much vegetation in drain, sides are steep and possibly lack vegetation, often with piles of dirt evident along drain) or natural (vegetation growing on banks and in drain, drain densely vegetated and does not look like it has been disturbed in quite some time)
Drain shape	A categorical variable indicating whether the drain was V-shaped (steep, depth usually greater than 1-2 m; width of water is narrow) or U-shaped (shallow, width of water in the drain is wider)

Brood routes, brood buffers and random buffers

Using ArcGIS Pro (v. 2.3.2, Esri Inc.), we created 'brood routes' by drawing a straight line from the nest-site through to consecutive brood locations (i.e., the relative path a brood used from hatch until brood fate was known; Figure 1). We assumed a straight-line trajectory between locations because we were unable to determine the actual path. Thus, if a brood had five observations, then the line ran through all five points in a chronological order. Associated 'brood buffers' were created by placing a buffer around this line (Figure 1). We used the 'adehabitat' package (Calenge 2006) in R*3.5.1 (R Core Team 2015) to investigate the distance moved between each consecutive brood movement retained in this analysis, and used this information to determine the appropriate buffer size that would encompass all habitats that the brood may have travelled through between observations. Mean movement of radio-marked brood-rearing females between consecutive observations was 226.4 m (SD = 421.4 m; range = 0 – 6006.9 m; n = 2128 movements); therefore, we used a 400 m buffer (200 m radius).
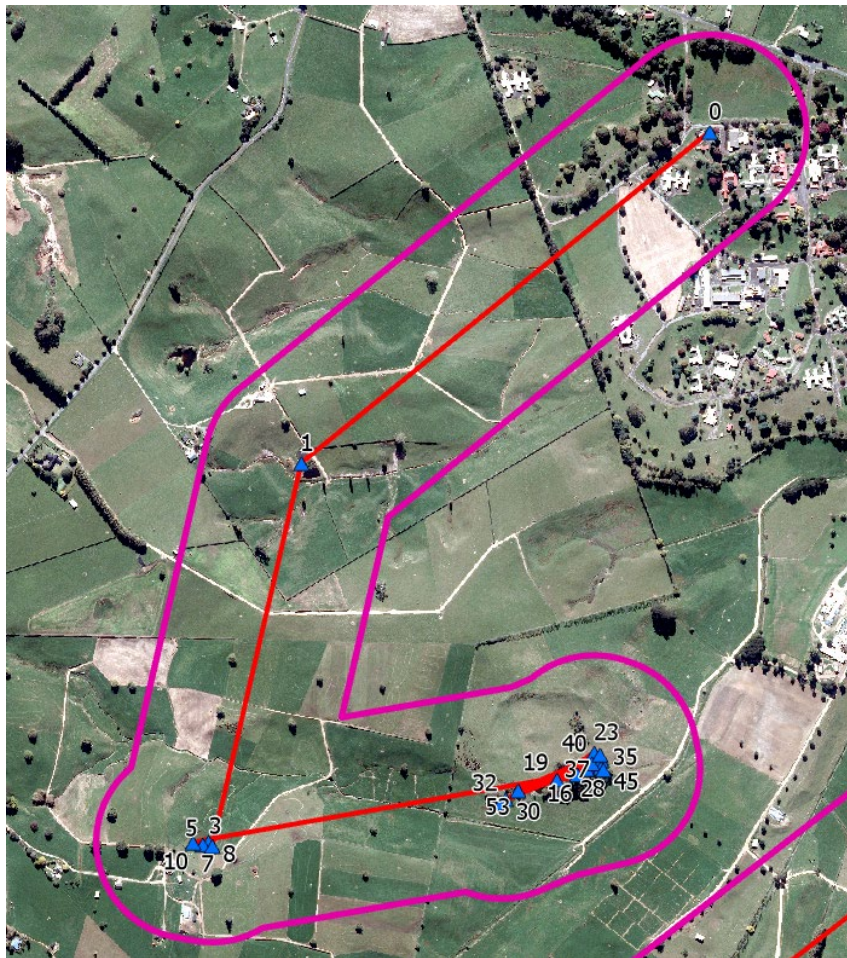
Figure 1 - Example of a brood route (red line) derived from brood location data of JU26 (blue triangles with days since hatch indicated for each point, where 0 = nest-site and hatch date) and the associated brood buffer (pink polygon) created by buffering the line by 200 m.

During the course of the study, we collected 2408 brood observations. We observed females up to three times following suspected brood loss and continued to track successful females until their batteries died or they left the study area; thus, some observations included location data of paired or flocked ducks which were no longer attending broods. Some observations indicated that females were on brood breaks as they were seen alone or paired, and often flushed and flew away from observers without acting broody, circling overhead or returning to the location after the observer immediately left the area. To remove potentially erroneous brood-location data (e.g., brood breaks, pairs, flocks, or other observations taken following brood failure) from our creation of brood buffers, we excluded observations from brood routes if: i) the female was seen flocked ($n = 26$) or found dead ($n = 1$) following suspected fledging (i.e., approximately 60 days or beyond); ii) observers already suspected the brood was lost during the previous observation and subsequent observations confirmed loss ($n = 228$; i.e., if the female was seen with ducklings on day 8, but 0 ducklings on days 10, 12 and 15, then we included days 8 and 10 but excluded days 12 and 15); iii) the female went missing for <5 days but reappeared with a drake or in a flock ($n = 2$; i.e., the last observation included was when the female was with the brood), or; iv) the female was on brood-break, as determined by her being in an unusual spot alone and flying away and not returning or circling (i.e., acting as though she had no brood), but was seen with ducklings on the following observation ($n = 21$). We retained all observations where observers did not see the brood and/or female, but the female acted broody or observers indicated that they felt the brood was still alive.

To evaluate habitat selection of brood buffers, we followed methods of Bloom et al. (2011) and created 'random buffers' by randomizing the direction of the original brood route while keeping it anchored on the nest-site and maintaining the original shape of the brood buffer. To reduce overlap with the brood buffer, buffers were duplicated and then randomly rotated 90-270 degrees away from the original brood buffer and assigned as the random buffer. To do this, we exported a shapefile from ArcGIS Pro that included the geometry and spatial-attribute information of each nest-site (anchor point) and brood buffer and read these layers into FME Desktop (Safe Software Inc. 2018). We used the *random* function in Microsoft Excel to randomly generate a number between 90 – 270 degrees for each brood buffer and derived brood-buffer-specific rotation angles, which we then included in the FME layers and used the *feature rotator transformer* in FME to rotate each buffer around the anchor point (nest-site). Random buffers were anchored to the nest-site because brood-rearing habitat is constrained by nest location and we wanted to compare habitat selection patterns to other available routes from the nest-site (Figure 2A).

Anchoring the random buffer on the nest created complete overlap between the 'brood buffer' and 'random buffer' within a 200 m radius of the nest-site. To alleviate masking patterns of habitat selection as a result of this overlap, we followed methods of Bloom et al. (2011) and split the 200 m radius nest-buffer into two equal parts. We either split the buffer by drawing a straight line through the buffer from the point where the two buffers diverged (Figure 2B), or if the brood route was rather convoluted, we split the buffer such that the majority of brood locations that were within a 200 m radius of the nest-site were contained to one half of the buffer. We allocated each half of the nest-buffer to either the brood buffer or

random buffer (whichever made most biological sense based on the brood route). This method reduced the overlap between brood and random buffers from 38% (SD = 21%, range = 0 – 99%) to 14% (SD = 18%, range = 0 – 75%); similarly to Bloom et al. (2011), we retained the remaining overlap. This overlap increased when broods stayed within close proximity to the nest during the entire duration of brood-rearing (Figure 3A) or moved in more than one direction around the nest-site (Figure 3B). Additionally, due to the density of nests and the size of brood buffers, particularly in Southland, overlap between nearby brood and random buffers was inevitable (Figure 4). Thus, brood buffers overlapped with 181 other brood buffers and 178 other random buffers; mean percent of this overlap was 22% and 23%, respectively.

Figure 2 - Example of a: A) brood buffer (purple outline) and random buffer (orange outline) created by randomly rotating the buffer 90-270 degrees while remaining anchored on the nest-site of ES06, and B) splitting the nest buffer into two equal halves. The northern (top) portion of the nest buffer is then attributed to the brood buffer (blue polygon) while the southern (bottom) portion is attributed to the random buffer (pink polygon).

Figure 3 - Example of excessive overlap between brood (purple polygons) and random (orange polygons) buffers where: A) the brood remains close to the nest-site of ES10 and B) the brood moves in several directions around the nest-site of WP31.
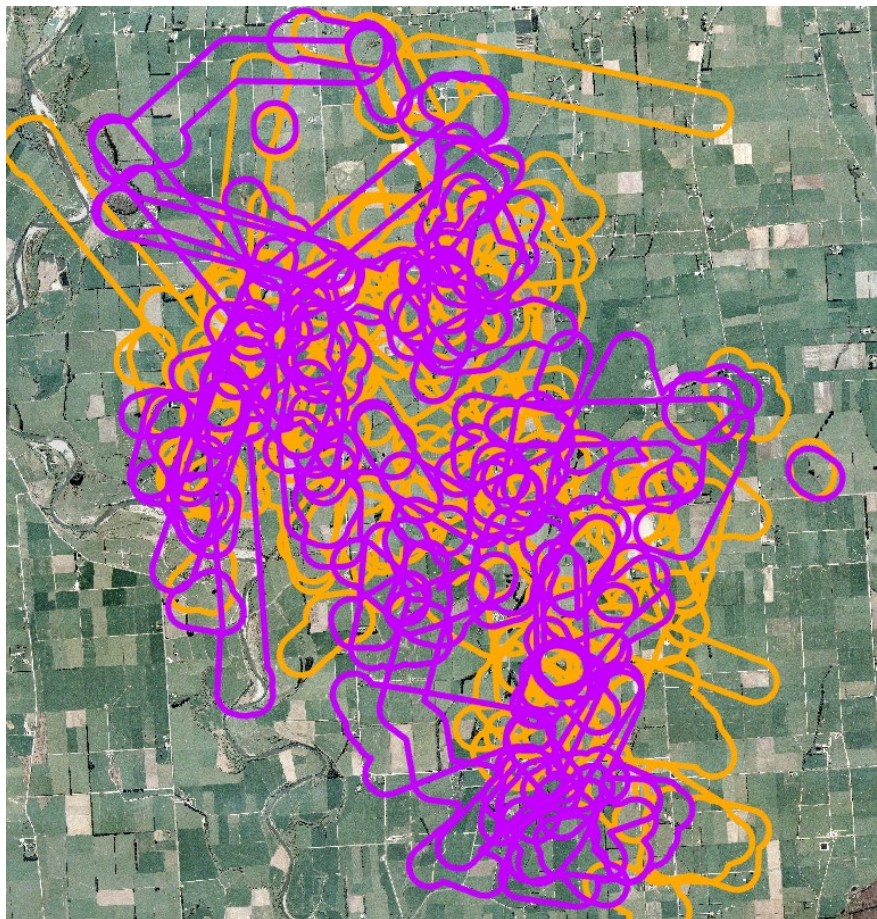
Figure 4 - Illustration of overlap between brood buffers (purple polygon) and random buffers (orange polygon) in Southland.

Geospatial classification

Prior to this study, a portion of geospatial data from both study sites had already been digitised using the same data layers and aerial imagery. E. Garrick (2015) digitised brood habitat throughout Southland's 2014 study area, which included broad categories for water and vegetation as well as paddocks. Cosgrove et. al (2015) digitised habitats within 400 m and up to 1600 m of nest-sites in Waikato, whereby, habitat types were further defined as pond, lake, effluent pond, hedgerow, woody cover, and individual trees and houses were also digitised. Finally, Sheppard (2018), digitised additional areas around nest-sites in Southland and Waikato but classified the habitat into broad categories of water, road or woody vegetation.

We collated all the digitised habitat data from these former studies, classified or re-classified specific habitat types where necessary, and digitised the remaining 'un-digitised' portion of the brood and random buffers. We used habitat information collected during brood observations (e.g., dominant habitat type, width of drain), to better inform aspects of aerial imagery and to ground-truth habitats that had already been digitised and classified. Thus, we assigned habitats into one of five types, which were further divided into sub-types (Table 2).

Data sources - We imported aerial imagery with a resolution of 0.75 m (SOU) and 0.50 m (WAI) and data layers for roads and highways, lakes, major rivers, and waterways from Land Information NZ Data Service (LINZ), and thematic classification of land cover from the Landcover Database v. 4.0 (Land Resource Information Systems Portal, Landcare Research. 2011–2013) into ArcMap (former studies; v. 10.3, Esri Inc.) or ArcGIS PRO (this study; v. 2.3.2, Esri Inc.) to aid in the digitisation of each study area (1: 5,000 scale). We chose to use imagery and geospatial data from 2012 – 2015 because this better reflected environmental and habitat conditions at the time of the study and avoided incorporating landscape modifications that have occurred in recent years.

Road areas – Using the digital map data from the LINZ topographical 50 series that depicted road centrelines, we digitised road area by assuming that all primary roads (e.g., paved roads) were 7.5 m wide (3.25 m lane + 0.5 m shoulder) and that motorways were 12 m wide (DTR 2016). Remaining road areas including secondary roads (i.e., gravel roads not included in LINZ centreline data) and races were digitized from aerial imagery.

Water/aquatic areas – Polygons for major rivers and lakes were imported from LINZ topographical 50 series for each study area. To digitise streams, creeks and some drains, we imported the Hydrographic Waterways Centreline shapefile from NIWA, used aerial imagery to determine the respective width of these waterways (range = 2 – 20 m wide) and their associated riparian margins (range = 0.5 – 20.0 m wide), and independently digitised them using the *buffer* tool in ArcMap 10.3. We identified and digitised artificial ponds (including effluent and stock ponds), additional drainage ditches and other waterbodies from aerial imagery or during the course of field work.

Vegetation – From the Landcover Database, we extracted polygons for dense vegetation which we defined as: broadleaved or deciduous hardwoods, gorse, manuaka (*Leptospermun*

scoparium) and/or kānuaka (*Kunzea ericoides*) stands, flax-dominated swamp, herbaceous freshwater vegetation, and indigenous, exotic and harvested forests. We buffered the riparian habitats of drains, streams, creeks, rivers, ponds, lakes, and roadside habitat at 2.5 m (in accordance with aerial imagery) and also include this as dense vegetation. Then, we digitised the remaining areas of dense vegetation (e.g., hedgerows, treelines, shelterbelts, scrub/shrublands and rank grass) from aerial imagery or during the course of field work. Finally, we classified dense vegetation as either: rank grass, woody (shrub/tree), hedgerow (including shelterbelts), and sedge/rush.

Paddocks – As part of her MSc. research, E. Garrick had digitised paddocks in Southland in 2014 and had classified them as 'short' or 'long' in accordance with the type of farming operation (e.g., sheep vs. dairy). We brought forth this layer and retained the classification scheme for the already digitised paddocks. We then digitised all remaining paddocks and classified these as unknown.

Anthropogenic – We used aerial imagery to digitise and classify anthropogenic areas including rural farmyards, dairy sheds, urban and rural residential properties, orchards and industrial areas such as airports, gravel pits and event space. In Waikato, a railroad ran through the middle of the study area, so we also imported a data layer for Railroad Centrelines from LINZ topographic maps, buffered it by 5 m in accordance with aerial imagery and assigned it as anthropogenic.

Table 2 - Definition of each habitat sub-type

Sub-type	Definition
Water	
Drain	A linear feature of water, often located between two paddocks, but sometimes associated with hedgerows or other linear strips of vegetation.
Pond	A relatively small body of water located within a paddock or vegetated area. Includes man-made and artificial ponds. Areas such as refuges and swamplands were also classified as ponds.
Lake	Lakes are relatively large, natural, waterbodies with evident inflows and outflows. There were no lakes in Southland, only in Waikato.
River	A large meandering body of water that is often wide (<15 m). One river runs through Southland and two rivers run through Waikato study areas.
Stream/creek	Streams and creeks differ from drains in that these bodies of water generally meander and are not linear. In Southland, differentiating streams from drains was difficult because the area is riddled with modified streams which have been straightened. These are generally wider than drains but have flowing water and gravel beds. In Waikato, streams and creeks are distinctly different from drains and are often much wider, surrounded by wide riparian vegetation, meandering and connect to nearby rivers.
Effluent	Effluent ponds; often located within close proximity of a dairy shed. Differ from ponds in that these areas are generally widely fenced and closer to races and dairy sheds.
Road	
Primary paved	Main highways and paved roads.
Secondary	Includes driveways, lanes, gravel roads and right-of-ways.
Race	Races or pathways located throughout farms by which livestock travel or farm personnel use on occasion. Differs from secondary roads in that races are always unpaved, generally narrower and located on private land.
Vegetation	
Rank grass/forbs	Includes rank grass along roadsides, near waterbodies or in open fields where shrubs were absent. We also included forbs in this category, which are herbaceous flowering plants such as clover, legumes, plantains, onions, daffodils, etc.
Woody cover	Includes trees, blackberry, gorse and other woody cover or scrubland. Basically, any area that was not a paddock or rank grass was often woody cover. Height of woody cover could range from low-lying woody ferns and shrubs to tall, large poplar or macrocarpa trees. At the brood-buffer scale, woody cover also included toetoe/pampas and flax, which provide thick, dense cover similar to other shrubs.
Hedgerow	A hedgerow was often located between two paddocks or bordered a road. In Waikato, hedgerows were distinctly different from trees in that trees often grew sparsely or in thick, irregularly shaped stands. In Southland, trees and hedgerows were often synonymous as there were linear hedgerows of large trees in some places (i.e., shelterbelts). In these instances, we attempted to classify hedgerows as <3 m high and trees/woody cover as >3 m.

Table 2 - continued

Sub-type	Definition
Sedge	Often located near low-lying water. Sedges were difficult to quantify but were often 'yellow-orange' in the aerial imagery. Most sedges were digitised based on brood information or knowledge of the study areas. Sedges included rushes, raupō and carex.
Paddock	
Short	A classification of paddock provided by E. Garrick (2015) to reflect sheep farms. Because we did not possess the knowledge of which paddocks in Southland were long or short, only those already classified were brought forth. Thus, all other paddocks were classified as 'unknown'.
Dairy	A classification of paddock provided by E. Garrick (2015) to reflect dairy farms. Because we did not possess the knowledge of which paddocks in Southland were long or short, only those already classified were brought forth. Thus, all other paddocks were classified as 'unknown'.
Unknown	All other paddocks throughout Waikato and Southland.
Anthropogenic	
Orchard	Orchards included any area containing fruit trees or kiwifruit.
Rural farmyard	Includes areas near dairy sheds, half-round barns, or houses located outside of townships, or other open areas where machinery, equipment or buildings were located.
Dairy shed	Where cows were milked once to twice daily. From the aerial imagery, we are unable to determine active versus inactive sheds.
Urban residential	Houses and yards that are located within townships such as Ohaupo, Te Awamutu and Lochiel. Urban residential and rural farmyard could be synonymous.
Industrial	Other anthropogenic areas such as railroads, airports, gravel yards, or event grounds (i.e., Mystery Creek event space in Waikato).

Local-scale habitat use

Because water is such an important resource for broods, we wanted to assess which waterbody-specific attributes improved duckling survival. Unfortunately, such information was only recorded during brood observations that occurred in or near waterbodies (i.e., nearly a third of all brood observations were in upland habitat such as farmland and fields and lacked this information; *see Results and Appendix 1*).This information focused on small spatial scales (i.e., within 5 m^2 of the brood) and information pertaining to entire waterbodies (i.e., characteristics of the entire pond or drain) were not recorded. We found some inconsistencies in measured local scale variables (*see Appendix 1*). To increase our understanding of local-scale habitats, reduce observer bias and use some of the data that had missing or inconsistent information, we related duckling survival to two different spatial scales of local habitat use: i) 'third-order habitat use' of the nearest waterbody, and ii) 'fourth-order habitat use' of the habitat where the brood was observed.

We assessed 'third-order habitat use' of waterbodies that were used by broods or that were in the closest proximity to broods observed in upland habitats away from water (i.e., in a paddock or field). Although broods were not always observed in or near aquatic areas, they

presumably used the drains, ponds and other waterbodies that were nearby and within their brood buffer. Thus, we used the *near* tool in ArcGIS Pro to identify waterbodies (e.g., drains, streams, river, ponds, lakes and effluent ponds) that were nearest to each brood observation ($n = 303$), created a subset of these waterbodies and then assigned waterbody-specific characteristics based on data combined from aerial imagery, brood observations and field experience. We used the *near* tool to calculate the distance from each brood observation to the nearest waterbody and extracted the area of the waterbody from the digitized polygon. Because the number of brood observations at any given waterbody ranged from 1–124 (*see Results*), we pooled information from all available observations to determine waterbody-specific characteristics. For categorical variables (e.g., vegetation type, cover type, drain type and drain shape) we assigned type and shape as the mode of all observations recorded at the waterbody (i.e., used the value recorded for the majority of the observations). If two categories were equally abundant, we referred to comments and assessed aerial imagery to aid in our decision. If there were incongruities about whether a habitat was fully fenced or not, we assigned it as partially fenced. For continuous variables (e.g., vegetation height, overhead cover, emergent cover, riparian width, drain width, drain depth) we used the average of all observations that had a value indicated. If all the information was absent/missing from available brood observations or there were no observations recorded at the waterbody (i.e., brood was near the pond but in the paddock), we: i) checked whether vegetation type, height, overhead cover and height of nest above water had been recorded on vegetation cards of any nearby nests; ii) inferred the information from nearby features or aerial imagery (vegetation type, cover type, vegetation height, overhead cover, emergent cover or drain depth only), iii) measured the distance from aerial imagery (riparian or drain width only), iv) estimated information based on experience at the site, or, v) assigned a null value. Some streams or drains extended almost entirely through the study site, but riparian vegetation and/or landscape characteristics tended to change as the stream progressed. In these instances, we separated the areas of the stream/drain that had homogenous habitat from areas where the habitat differed (Figure 5).

Figure 5 – Examples of splitting the stream into two different polygons consistent with the change in habitat type around the riparian margin.

We assessed 'fourth-order habitat use' of the local-scale habitat characteristics that were consistently collected for each brood observation (e.g., habitat type, vegetation type, vegetation height and overhead cover). We assigned habitat type to one of eight categories: roadside, drain, stream, pond/lake, effluent pond, linear upland, non-linear upland and paddock and assigned vegetation type to one of six categories: rank grass, paddock grass, sedge, non-woody, woody or none (Table 3). During brood observations we did not distinguish between ponds and lakes, so these two waterbodies were grouped together for this analysis. We used the raw values of vegetation height and overhead cover that were recorded for each observation.

Table 3 – Habitat variables collected at the local-scale (within 5 m²) for all brood observations

Variable	Description
Habitat type	
Road	Roadside habitat, typically rank grass along a paved road
Drain	Drainage ditch; a straight-linear habitat that was typically surrounded by paddocks or bordering a road or drain
Pond	Includes natural and man-made ponds, lakes, swamps, refuges sites and other irregularly shaped polygons of water, but excludes effluent ponds and ephemeral water. Includes observations taken when the brood was in the pond or in the riparian area of the pond.
Stream	A linear habitat that typically meandered through numerous properties; includes rivers, creeks and other linear waterbodies. Includes observations taken when the brood was in the stream or in the riparian area of the pond.
Effluent pond	Dairy effluent pond
Linear upland	Straight-linear upland habitat such as hedgerows and shelterbelts; includes all types of hedgerows (flax, toetoe, hawthrone) and shelterbelts.
Non-liner upland	Irregularly shaped upland habitat such as woodlots, wood/shrub fields and farmyards
Paddock	An area of intense grazing
Vegetation type	
Rank grass	Includes rank grass and forbs; ungrazed introduced pasture species
Paddock grass	Unless otherwise indicated on the brood observation form, we assumed all observations within a paddock had short grazing grass/forb species such as cocksfoot or clover
Sedge	Includes any sedge, rush or emergent vegetation, such as raupō, carex, azolla and duckweed
Non-woody	Includes tall grasses (pampas and toetoe) and dense, non-woody vegetation, such as flax and lily of the valley
Woody	Includes wooded-stemmed vegetation such as trees and shrubs, such as blackberry, gorse, hedgerows, pine trees, eucalyptus, macrocarpa and fern trees
None	Assigned this category if the bird was flying and not seen on the ground, found on bare ground or leaf litter, or using an artificial environment such as a shed, nest-box or silage bail
Vegetation height	The maximum height of the vegetation within 5 m² of the brood
Overhead cover	The percent of canopy cover protecting the brood from aerial observers/predators

Data considerations – Habitat type was not recorded for four observations and 25 observations indicated the habitat type was 'other'. For these observations, we assigned the habitat type based on observer comments or referring to aerial imagery. There tended to be numerous discrepancies between whether certain linear waterbodies were drains or streams, despite multiple observations at each location. To ensure brood observations at these locations all listed the same habitat type (i.e., either drain or stream), we extracted the habitat type from GIS following collation of the brood observation data, and changed the habitat type of 122 brood observations from drain to stream or vice-versa. Also during this exercise, we

changed the habitat type of 29 observations from streams to ponds (these were refuges and swamp areas that had originally been classified as streams but which we classified as ponds due to their irregular shape and size) and we also changed the habitat type of 14 observations which has been erroneously entered as drain or stream when in fact they were something else (i.e., paddock, ephemeral, or upland linear).

Vegetation type was not recorded for 376 observations and was recorded as other or unknown for 26 observations. Here, we assigned vegetation type based on: field notes and comments provided during brood observations ($n = 103$), the habitat type that bird was in (i.e., if the bird was in paddock or effluent pond we assumed the predominate vegetation was grass, or if they were in a woody field or hedgerow we assumed vegetation was shrubs; $n = 71$), a combination of aerial imagery and nearby brood observations that were recorded in the same habitat type ($n = 158$), or aerial imagery only ($n = 68$).

The first observation interval begins at the nest-site, so for 196 first observations we assigned the habitat and vegetation type as indicated by the vegetation measurements taken at the nest-site ($n = 186$), from comments made on the nest card ($n = 5$), from information obtained from both vegetation measurements and the nest card ($n = 3$) or from aerial imagery ($n = 3$). Vegetation height was also recorded during vegetation measurements at the nest-site so we used these values for the first observation interval. Overhead cover at the nest-site was recorded as either full, partial or no canopy cover. Thus, we inferred that full, partial and no canopy cover equated to 100%, 50% and 0% overhead cover, respectively. Vegetation height and overhead cover were not reported for 28 and 21 nests, respectively. For these values, we assigned the mean vegetation height and overhead cover of the remaining nest-sites ($\bar{x}$ Vegetation Height $= 126.9$ cm, SD $= 289.2$ cm, $n = 427$; $\bar{x}$ Overhead Cover $= 16\%$, SD $= 37\%$, $n = 433$).

For 57 records that had vegetation height > 1000 cm, we assumed that the measurement had erroneously been recorded in mm and converted it to cm. Vegetation height and overhead cover were not recorded for 677 and 611 brood observations, respectively (28% and 26% of all observations). Because these were brood-specific events and measurements were meant to be recorded within 5 m^2 of where investigators observed the brood, we were unable to infer missing measurements from other nearby brood counts. Instead, we assigned values of 0 for missing measurements of overhead cover because 44% of reported overhead cover measurements was 0 (and using the mean value would likely have inflated and biased results), and assigned the mean value for missing measurements of vegetation height ($\bar{x} = 100.68$ cm ; SD $= 154.13$; $n = 1979$).

Of the 303 waterbodies that were nearest to all brood observations, we were able to calculate the distance to each waterbody, the size of each waterbody, and the riparian width around each waterbody. However, we did not know the percent of emergent cover for 20 waterbodies, so we assigned the mean value based on the remaining waterbodies ($\bar{x} = 32.7\%$, SD $= 28.6\%$, $n = 308$). We also did not have location information for two observations for one brood in Waikato (JU08); but, as determined from a 100% minimum convex polygon of the five known locations and the four latter locations, the 'home-range' of this brood was

5.75 ha and 0.10 ha, respectively. Thus, we assigned the missing values based on the average value recorded at the known locations and assigned habitat type as drain because the other observations all occurred in nearby drains.

Model design and covariates

As opposed to creating a global model containing all habitat parameters and eliminating uninformative parameters from the candidate set to determine the top model using model selection and Akaike's Information Criterion, we carefully chose models and covariates *a priori* based on: previous research, results from the habitat selection analysis which we ran concurrently and interest from the client. We defined supported covariates as those with coefficients that had 95% credible intervals that did not overlap zero, and based our interpretations on parameter estimates and standard errors derived from each model.

Habitat selection

We evaluated two models of habitat selection (Table 4). First, we investigated whether the overall habitat composition differed between brood and random buffers; thus, we incorporated the proportion of water, roads, dense vegetation and anthropogenic habitats. Secondly, we investigated whether the proportion of manageable habitat types (i.e., everything except paddocks and anthropogenic habitats) differed between brood and random buffers. Thus, we evaluated the proportion of drains, ponds, effluent ponds, streams, rank grass, woody cover, hedgerows, and sedge habitat. Because female age and study site were important predictors of duckling survival (Sheppard 2018), we initially ran an exploratory model to evaluate whether female age or study site affected habitat selection; neither variable explained habitat selection (β_{Age} = -0.12, SE = 0.22, 95% CI: -0.55, 0.32; β_{Site} = 0.19, SE = 0.23, 95% CI: -0.27, 0.64) so we excluded these covariates from all additional analysis.

Duckling survival

We included two types of covariates in our survival models: i) covariates that were brood-specific, such as the proportion of water within the brood buffer (i.e., variables that remained constant throughout the life of the brood) and, ii) interval-specific variables, which were covariates that were recorded during each observation or that were averaged during the time between each consecutive brood observation (i.e., variables that changed each time the brood was observed such as the percent of overhead cover or age of the brood). For instance, a brood on day 1 may have been in a drain with 25% overhead cover and on the following observation on day 4 the brood may have been in a paddock with 0% overhead cover. As further explained in the *statistical analysis section*, our model was designed to estimate survival while examining interval-specific covariates.

We investigated six models of duckling survival (Table 4). First, we related duckling survival to the general habitat model (Model 1) that we evaluated as part of the habitat selection analysis, thus we included the proportion of water, roads, dense vegetation and anthropogenic areas within the brood buffer, as well as interval-specific water balance. At the request of the client, we included interval-specific water balance because values above 0

indicate groundwater saturation and may indicate ephemeral water. Daily water balance deficit was calculated as:

$$Water\ balance\ deficit_t =\ Rain\ Deficit_{(t-1)} +$$

$$Penman\ Potential\ Evapotranspiration_t - Rainfall_t$$

Where, *t* is the date of the brood observation. To determine interval-specific water balance, we averaged the water balance deficit between each brood observation. For instance, if the brood was observed on day 1 and then again on day 4, water balance deficit for the first observation interval would be the average of the water balance deficit recorded from days 1-3. Measures of daily rainfall and Penman's potential evapotranspiration data were obtained from the National Climate Database (National Institute of Water and Atmospheric Research Ltd, 2015, cliflo.niwa.co.nz), using data collected from the nearest weather station which had data available for each study site (Southland: Winton2, Agent no. 5768; Waikato: Hamilton Ruakura Ews, Agent No. 26117). We used Hamilton Ruakura station as opposed to the nearer Hamilton Aws station because data for Penman's Potential Evapotranspiration was unavailable from the latter.

We assessed whether habitat selection (at the brood-site scale) was adaptive (as is expected) or if there were evidence of perceptual ecological traps, whereby mallards failed to select beneficial habitats. To do this, we incorporated our results from the habitat selection analysis and evaluated a model containing the habitats selected by broods (Model 2) and another model containing habitats that were not selected by broods (Model 3; as determined from our analysis of habitat selection).

Given the importance of aquatic habitats for broods, our fourth model (Model 4) examined interval-specific characteristics of the nearest waterbody during each brood observation and related these to duckling survival to determine if smaller-scale habitat use conferred survival benefits (third-order habitat use). Unfortunately, due to our small sample size of broods (*n* = 190) our models are unable to accommodate a large number of variables, so we carefully considered which waterbody characteristics might be most important for broods and selected habitat variables which had large amounts of available data and which we deemed important for duckling survival based on experience and previous literature: distance to the nearest waterbody, waterbody area, waterbody type, width of the riparian margin and percent of emergent cover. We elected not to assess vegetation height and overhead cover in this model but included it in Model 5 instead. We omitted the categorical variables of cover type and whether the waterbody was fenced, because there was little variation among the categories (i.e., 60% and 77% of all observations indicated that cover type was 3 and that habitats were fully fenced, respectively).Only four broods were observed solely in drains and because our model requires interval-specific observations and less than 20% of all observations occurred in drain habitat (*see Results*), we were unable to further assess drain-specific characteristics (e.g., drain width, depth, shape and maintenance) due to insufficient sample size and the requirements of the model parameters (i.e., the model would require that most broods use/inhabit drains during nearly every observation).

Finally, we related interval-specific information collected during brood observations (fourth-order habitat use) to evaluate whether the type of habitat, type and height of vegetation and percent of overhead cover within 5 m^2 of the broods' location at the time of the observation affected duckling survival. Originally, we had hoped to include habitat type and vegetation type in the same model, but the excessive amount of categories results in convergence failure (i.e., the model was overfit). To facilitate convergence, we retained vegetation height, overhead cover and habitat type in Model 5, but included only vegetation type in Model 6.

Although Sheppard (2018) found that daily duckling survival increased with female age and was greater in Southland, we did not include female age or study site in our analysis of duckling survival because: these variables had no influence on habitat selection, the influence of age and site on brood and duckling survival is already well understood and our small sample size of broods necessitated that the number of parameters in each model be reduced as much as possible. However, we included other covariates that have previously been shown to affect brood and duckling survival or detection (Sheppard 2018); we included brood age as a covariate in our analyses of duckling and brood survival and duckling detection, and included effects of study site (Southland and Waikato) and year (2014 and 2015) in our evaluation of brood detection. To facilitate convergence of Model 6, we omitted study site and year from the analysis and only included effects of brood age as a covariate in the analysis of duckling survival.

Table 4 - List of models used to evaluate brood-site habitat selection and duckling survival of mallards in Southland and Waikato, 2014–2015

		Model	Parameters
Habitat selection	1.	General habitat	Water + Roads + Dense vegetation + Anthropogenic
	2.	Manageable habitat	Drain + Pond + Effluent + Streams + Rank grass + Woody cover + Hedgerow + Sedge
Duckling survival	1.	General habitat	Water + Roads + Dense vegetation + Anthropogenic + Water balance deficit
	2.	Habitat selection	Drain + Pond + Effluent + Sedge
	3.	No selection	Stream + Grass + Woody + Hedgerow
	4.	Nearest waterbody characteristics	Distance to nearest waterbody + Waterbody area + Type of waterbody + Width of riparian area + Emergent cover
	5.	Local-scale habitat characteristics	Habitat type + Overhead cover + Vegetation height
	6.	Local-scale vegetation type	Vegetation type

Statistical analysis

We compared habitat composition using descriptive statistics including mean, standard deviation (SD), range, and one-way ANOVAs. We examined habitat selection using generalised linear models (glm) in R*3.3.0 (R Development Core Team 2015). We modelled response variables using a binomial distribution with a logit link and used the 'lme4' package (Bates et al. 2015) to incorporate random effects of brood identity.

To investigate duckling survival, we followed methods of Sheppard (2018), modelling duckling survival from interval-specific observation matrices of offspring counts and covariate information. We used a recently developed model structure fitted by a Bayesian framework that simultaneously examines daily duckling and brood survival, and individual duckling and brood detection (T. Arnold, University of Minnesota, unpubl. data). The model is an extension of the Cormack-Jolly Seber model and followed methodologies of Lukacs et al. (2004) such that broods were assumed to be independent and reliably associated with the marked female, but relaxed the assumption that all young are counted at every occasion. Further, the model assumed that broods were closed to immigration (i.e., brood mixing did not occur) and, after accounting for individual covariates, whole-brood mortality and observation failure, individual survival and detection probabilities of offspring were similar for each observation interval (T. Arnold, University of Minnesota, unpubl. data). The model allowed for irregular intervals between counts such that exposure days were equal to the interval size.

We used the exposure interval between two consecutive brood observations as the sampling unit, defined as an observation interval. We estimated interval-specific brood and duckling survival by treating consecutive brood observations as intervals. If a brood survived a given observation interval, then survival was reflected as interval-specific individual duckling survival, whereas if the brood failed during the interval (i.e., complete brood loss during a single event), individual duckling survival was irrelevant. If at least 1 duckling survived, brood detection probabilities were modelled using a single Bernoulli trial (0 = brood not seen; 1 = brood detected), and the probability of detecting an individual duckling was the product of brood and duckling detection probability. This method permitted the use of staggered survival data, irregular interval lengths and incomplete or missed brood counts (i.e., inability to detect all or some of the surviving offspring).

We implemented our models using JAGS (Plummer 2003) run through jagsUI (Kellner 2015) in R*3.3.0 (R Development Core Team 2015). We closely followed methods of Sheppard (2018) and assigned uniform priors from 0.5 to 1 for daily brood and duckling survival rates or 0 to 1 for brood and duckling detection probabilities; priors for survival and detection parameters were set on the real scale and then transformed to the logit scale (e.g., logit $(S) = \log(S/(1-S))$). For our covariates, we assigned uniform priors in the interval -2 to 2 (logit scale), and continuous covariates were standardised to have mean = 0 and SD = 1 to aid in model convergence. We ran 50,000 iterations of 3 MCMC chains and removed the first 5,000 iterations as burn-in. The posterior distribution was calculated from every fifth iteration (i.e., thin rate = 5), thus the joint posterior was determined from 27,000 samples. We assessed

model convergence by visually inspecting trace plots and ensuring all $\hat{R}$ values were < 1.1 (Gelman and Rubin 1992). We present graphical results of significantly important variables based on mean covariate values.

Brood and interval-specific covariates – For each observation interval we determined: the number of duckling observed, the number of days between observations (intervals), and the age of the brood at the beginning of each interval. In our analysis of models 1–3, we determined brood-specific habitat composition of buffers (e.g., proportion of water, roads and drains) as well as interval-specific water balance deficit averaged across interval length. In models 4, 5 and 6, all covariates were interval-specific (e.g., habitat type and distance to nearest water).

Data censoring – We followed data censoring and considerations of Sheppard (2018) and used the same brood and duckling data in our analysis. Thus, we combined two broods that became and remained amalgamated throughout the entire brood-monitoring phase and treated them as a single large brood because: i) they had the same hatch date; ii) telemetry data indicated that the two implant females remained together from capture until the end of the study; iii) nests were within 4 m of each other; and, iv) although individual broods could not be discriminated, adequate counts and information on the mixed-brood was obtained throughout the brood-rearing period. We censored all records of a 3rd brood which amalgamated with other unmarked brood(s) immediately following hatch because reliable counts could never be obtained. Aside from the three broods that mixed immediately following hatch, only 3% of observations reported brood-mixing. We censored counts of temporary brood amalgamations if it was impossible to obtain a reliable count of each brood. Four broods became habitually mixed after 41 or more days of age, so we right-censored these data to include only the observations prior to brood amalgamation ($n = 8$ observations). Eight females died during brood-rearing: 5 had ducklings < 21 days old at time of mortality; 2 were found dead at brood age 30, but were last reported alive at brood age 24 and 26 days, respectively; 1 died at brood age 60. Gendron and Clark (2000) reported survival of ducklings abandoned from 23 days of age, thus if a female died during brood-rearing, we assumed complete brood loss if ducklings were younger than 23 days. To evaluate detection, we retained partial counts and zero counts (i.e., no ducklings observed because of total brood loss or failed detection) in our analysis.

RESULTS

Brood routes, brood buffers and random buffers

Brood routes (e.g., the straight-line distance travelled between consecutive brood observations) averaged 2484 m (range = 19–24,139 m, SD = 2,616 m, n = 194). Brood routes tended to be longer when broods were tracked for longer durations (i.e., there were a greater number of observations per broods; F = 37.29, df = 1, 187, p<0.001) and when broods were successful (F = 40.63, df = 1, 183, p< 0.001; Figure 6A). Site-specific differences in the length of brood routes was not evident (F = 0.019; df = 1, 187, p = 0.89).

Brood buffers (e.g., brood routes with a 200 m radius buffer) ranged from 6.4–507.7 ha ($\bar{x}$ = 57.3 ha, SD = 53.0 ha). Brood buffers were also larger when broods were tracked for longer durations (F = 11.23, df = 1, 188, p<0.001) and when broods were successful (F = 12.89, df = 1, 184, p<0.001; Figure 6B).
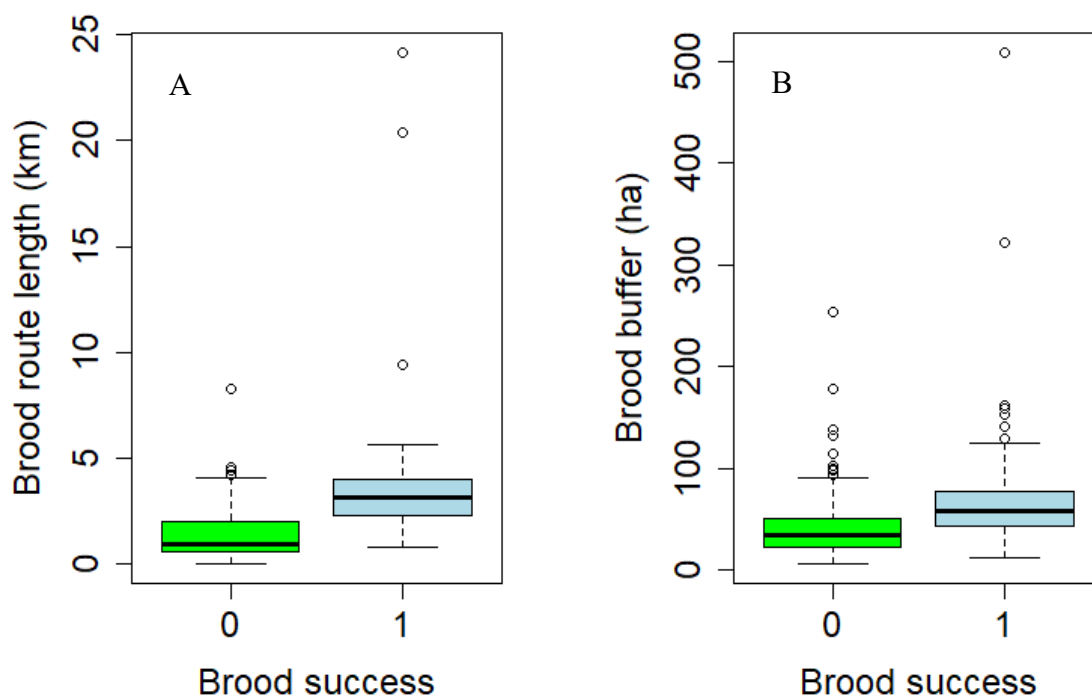
Figure 6 – Boxplot of A) brood route length (km) and B) brood buffer area (ha), comparing broods that failed (0; green box) to those that were successful and had at least 1 duckling fledge (1; blue box), showing mean length (black line), 25-75th quantiles (coloured boxes), 95% range (whiskers) and outliers (hollow dots).

Habitat composition of brood buffers

Overall, habitat composition of brood buffers contained 67% paddocks (SD = 0.22, range = 0.02 – 0.93), 22% dense vegetation (SD = 0.15, range = 0.04 – 0.75), 5% water (SD = 0.06, range = 0.00 – 0.57), 3% roads (SD = 0.00 – 0.54) and 3% anthropogenic areas (SD = 0.00 – 0.24) (Figure 7). The majority of dense vegetation was comprised of woody habitat (shrubs and trees) and rank grass; water/aquatic habitat consisted mostly of streams, drains and ponds; and, anthropogenic areas predominately consisted of rural residential properties (Figure 7). Compositional differences were evident such that buffers in Southland contained greater areas of dense vegetation and roads, but less paddocks, than buffers in Waikato (Table 5).
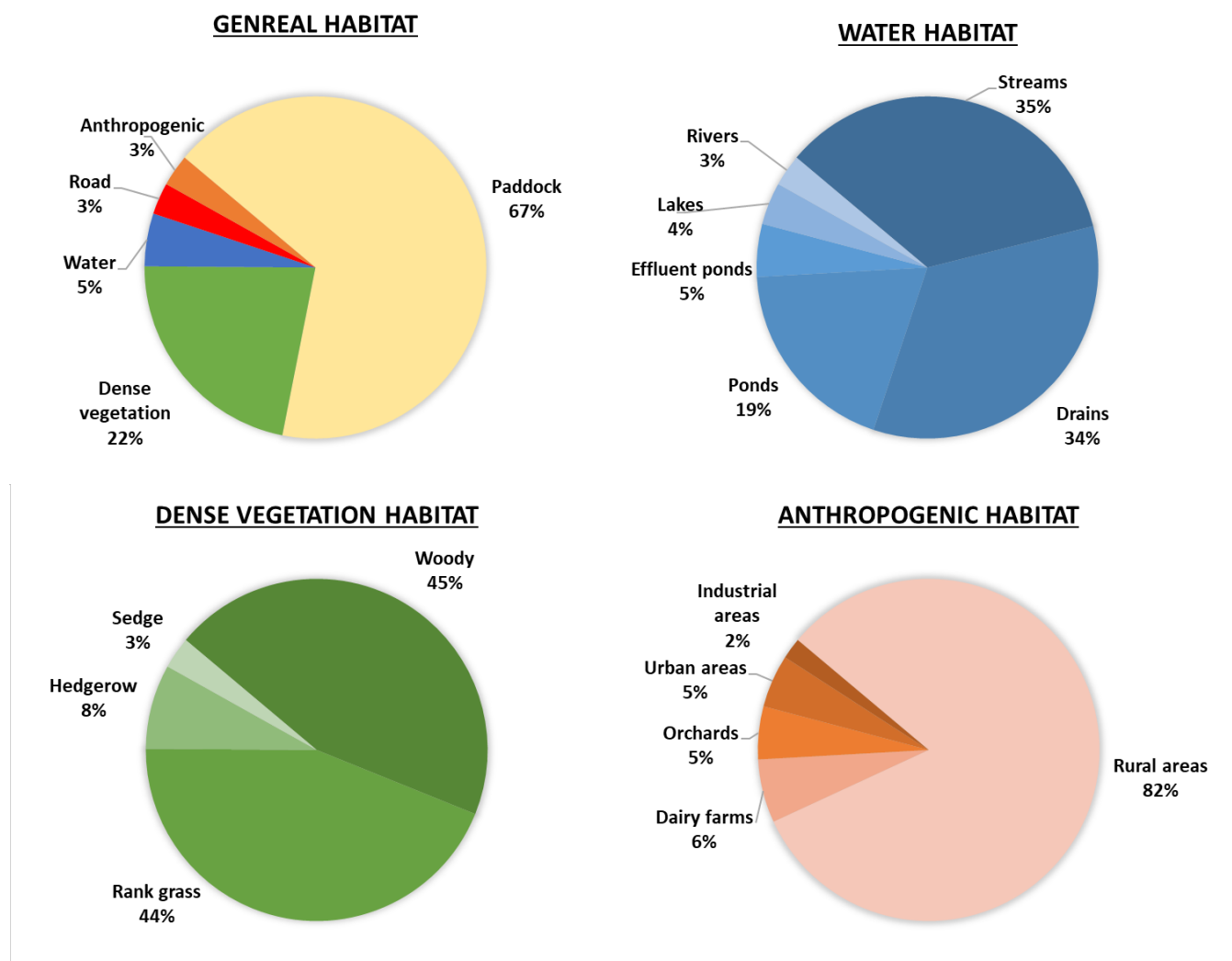
Figure 7 – Composition of habitats and habitat subtypes within brood buffers of mallards throughout Southland and Waikato, 2014–2015.

Table 5 - Differences in habitat composition ($\bar{x}$ +/- SD) of brood buffers in Southland and Waikato, showing F-stat and p-value derived from a 1-way ANOVA.

	Southland	Waikato	F[1]	P
Paddock	0.61 + 0.26	0.74 + 0.13	20.6	< 0.001
Dense vegetation[2]	0.27 + 0.18	0.16 + 0.08	27.97	< 0.001
Water[3]	0.06 + 0.05	0.05 + 0.07	1.063	0.30
Road[4]	0.05 + 0.07	0.02 + 0.02	9.37	0.003
Anthropogenic[5]	0.03 + 0.04	0.03 + 0.04	0.02	0.90

[1] df = 1, 191
[2] Dense vegetation = sum of rank grass, sedge, hedgerows, shrubs, trees and other woody cover
[3] Water = sum of drains, streams, rivers, ponds and lakes
[4] Road = sum of primary and secondary roads and races
[5] Anthropogenic = sum of dairy farms/sheds, urban and rural farmyards, orchards and industrial areas

Dense vegetation consisted of rank grass, woody habitat (trees and shrubs), hedgerows and sedges. Aside from sedge, buffers in Southland contained higher proportions of these habitat types than those in Waikato (Table 6). Although the average composition of aquatic habitats within brood buffers did not differ between sites (Table 5), buffers within Southland tended to have higher proportions of ponds and streams and lesser proportions of drains than those in Waikato; moreover, lakes were not present in Southland (Table 6). Finally, although buffers in Southland tended to have higher proportions of primary (highways) and secondary roads (other paved roads including driveways or main gravel roads), the proportion of races within the buffers was equal between sites (Table 6).

Table 6 - Differences in habitat type ($\bar{x}$ +/- SD) between brood buffers in Southland and Waikato, showing F-stat and p-value derived from a 1-way ANOVA.

		Southland	Waikato	F[1]	P
Dense vegetation	Grass	0.14 + 0.10	0.05 + 0.02	64.87	< 0.001
	Woody	0.11 + 0.10	0.09 + 0.06	3.82	0.052
	Hedgerow	0.02 + 0.02	0.007 + 0.006	14.19	< 0.001
	Sedge	0.0003 + 0.001	0.02 + 0.03	28.97	< 0.01
Water	Drain	0.007 + 0.009	0.011 + 0.007	11.30	< 0.001
	Pond	0.015 + 0.022	0.007 + 0.018	7.72	0.006
	Lake	0 + 0	0.02 + 0.07	6.32	0.013
	River	0.006 + 0.025	0.004 + 0.022	0.41	0.523
	Stream	0.024 + 0.025	0.005 + 0.013	43.46	<0.001
	Effluent	0.003 + 0.011	0.002 + 0.004	0.415	0.520
Road	Primary	0.013 + 0.023	0.007 + 0.006	6.56	0.011
	Secondary	0.007 + 0.017	0.003 + 0.009	5.49	0.020
	Race	0.025 + 0.06	0.014 + 0.007	3.04	0.083

Habitat selection of brood buffers

We assessed two models that described habitat selection at the brood-buffer scale (second-order habitat selection; Table 4). The 'general habitat model (Model 1)' suggested that broods exhibited strong selection when buffers consisted of at least 30% of water (Table 7; Figure 8). Parameter estimates of the remaining habitats suggested that brood buffers tended to have less dense vegetation and anthropogenic areas, but greater proportions of roads, than random buffers; however, these results were negligible (Table 7).

The 'manageable habitat model (Model 2)' indicated that broods selected brood-rearing areas with higher proportions of drains, ponds, effluent ponds and sedge habitat but no (or very weak) selection for streams, rank grass, woody cover or hedgerows (Table 7). Selection was strongest when drains, ponds, effluent ponds or sedge habitat constituted greater than 11%, 7%, 5%, or 13% of the brood buffer, respectively (Figure 9). Although 95% confidence intervals overlapped zero in regards to stream habitat, this result was marginal and overall, habitat selection patterns of stream habitat were synonymous to those of effluent ponds.

Table 7 – Beta estimates and associated standard errors (SE) and 95% lower and upper confidence intervals (LCI and UCI) for parameters (the proportion of a given habitat type within a buffer) in each model evaluating brood-site habitat selection of mallards in Waikato and Southland, 2014–2015, indicating whether selection was positive (+), negative and indicated avoidance (–) or not evident.

Model	Parameter	Estimate	SE	LCI	UCI	Selection
Model 1: General habitat	Intercept	0.07	0.11	-0.14	0.29	n/a
	Water	19.33	4.54	10.96	28.78	+
	Roads	3.27	3.48	-3.29	11.30	not evident
	Dense vegetation	-0.84	1.21	-3.25	1.52	not evident
	Anthropogenic	-2.08	3.18	-8.51	4.08	not evident
Model 2: Manageable habitat	Intercept	0.16	0.12	-0.07	0.40	n/a
	Drain	33.80	15.54	3.79	64.83	+
	Pond	62.29	15.07	35.12	93.84	+
	Stream	20.94	11.59	-0.95	44.48	not evident[1]
	Effluent pond	47.94	28.32	0.27	113.99	+
	Rank grass	2.34	2.73	-2.97	7.77	not evident
	Woody cover	-2.78	1.79	-6.38	0.68	not evident
	Hedgerow	-8.30	9.05	-27.04	8.70	not evident
	Sedge	26.30	11.46	5.11	49.93	+

[1] These results are marginally significant and could arguably be interpreted as evidence of habitat selection.
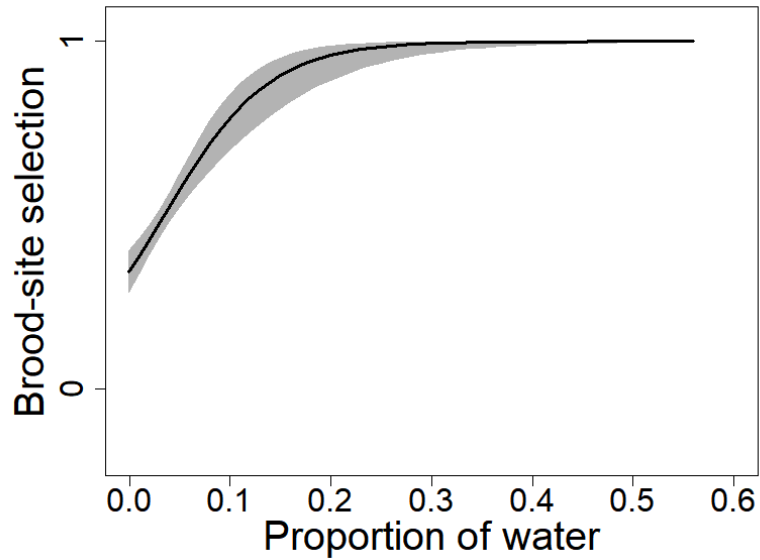
Figure 8 – Brood-site selection in response to the proportion of water (including drains, streams, rivers, ponds, effluent ponds, lakes and ephemeral waterbodies) within the brood buffer. Shaded area represents 95% confidence intervals.
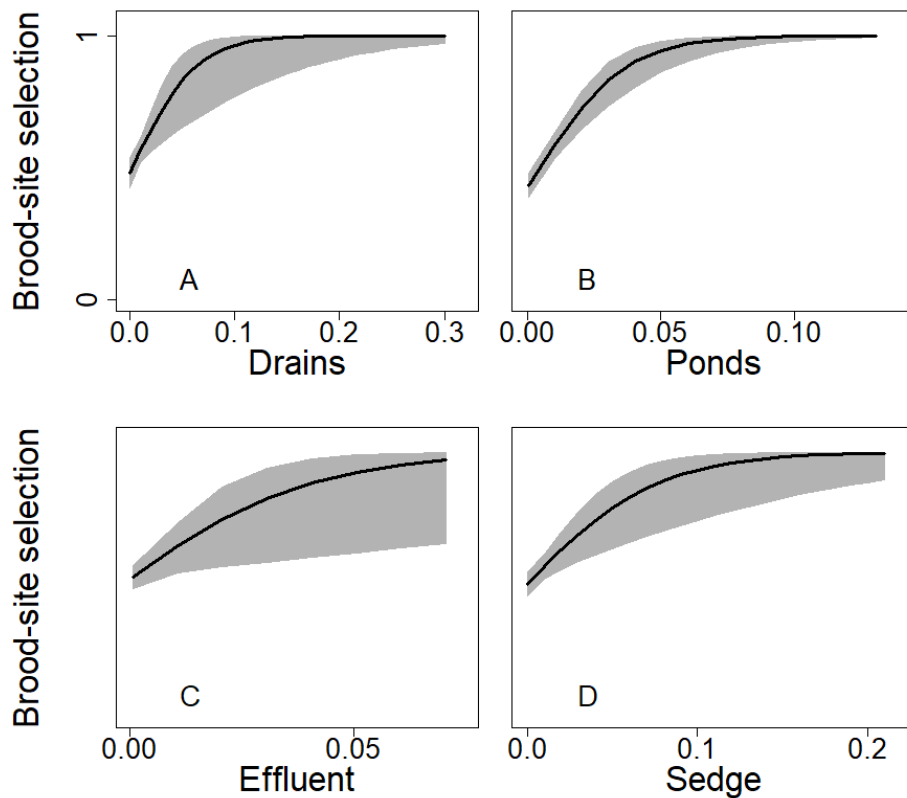
Figure 9 - Brood-site selection in response to the proportion of: A) drains, B) ponds and C) effluent ponds and D) sedge habitat, within the brood buffer. Shaded area represents 95% confidence intervals.

Habitat characteristics and use of the nearest waterbody

To investigate third-order habitat use, we assessed features of the nearest waterbody based on 2,411 locations of broods. We retained records of potentially erroneous location data and nest breaks because we wanted to encompass as many waterbodies in our analysis as possible. The number of observations that occurred at any given waterbody ranged from $1 - 124$ ($\bar{x} =$ 7.96, SD = 10.89; 124 observations were at Maesmor's Pond in Southland). We assessed characteristics of 303 waterbodies including 121 drains, 52 streams, 4 river segments, 77 ponds, 45 effluent ponds, and 4 lakes.

On average, brood observations occurred 36.0 m from the nearest waterbody (range = 0 – 496.8 m, SD = 74.6 m). Area of lakes and rivers exceeded that of other waterbody types, but streams and ponds tended to have larger areas than drains and effluent ponds (ANOVA: F = 53.2, DF = 5, 297, p<0.01; Figure 10; *Table 10 in Appendix 2*). Lakes, ponds and rivers had taller vegetation, greater percentage of overhead cover and wider riparian margins than drains, effluent ponds or streams (ANOVA $_{\text{Vegetation Height}}$: F = 13.8, DF = 5, 276, p < 0.01, Figure 11; ANOVA $_{\text{Overhead Cover}}$: F = 7.8, DF = 5, 284, p < 0.01, Figure 12; ANOVA $_{\text{Riparian Width}}$: F = 63.1, DF = 5, 297, p < 0.01, Figure 13; *Table 10 in Appendix 2*). Lakes and drains had ~50% emergent cover, ponds and streams has ~25% emergent cover and effluent ponds and rivers had <10% emergent cover (ANOVA: F = 12.7, DF = 5, 279, p < 0.01; Figure 14; *Table 10 in Appendix 2*).
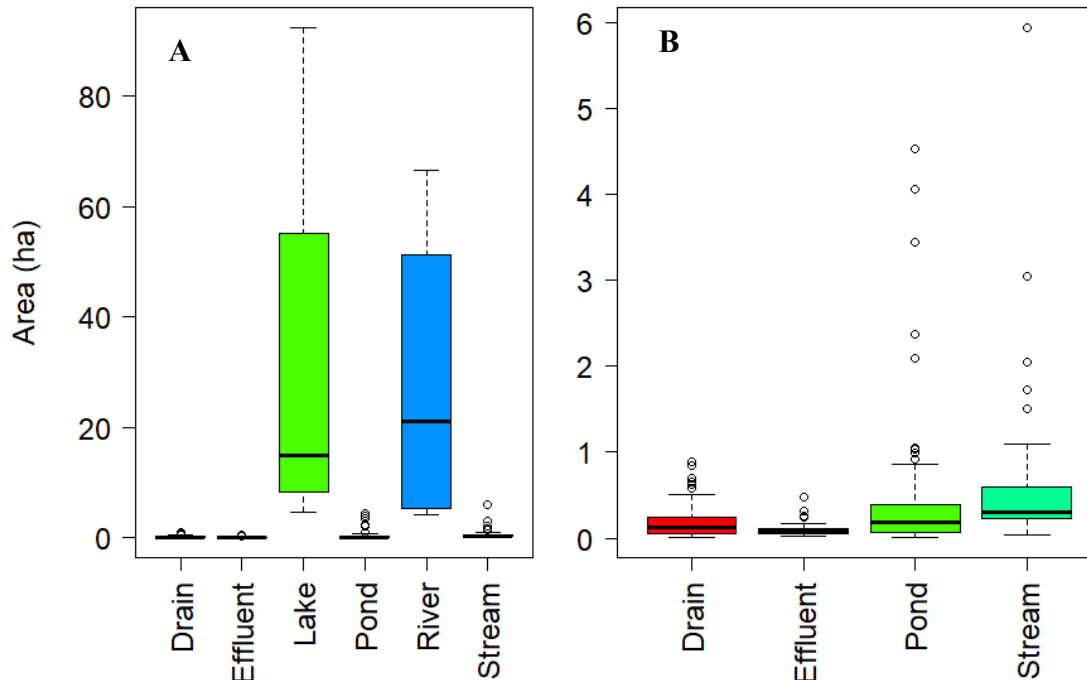
Figure 10 - Boxplot of area (ha) in relation to waterbody type, showing mean height (black line), 25-75th quantiles (coloured boxes), 95% range (whiskers) and outliers (hollow dots), as determined from 303 waterbodies that were in the nearest proximity of 2411 brood observations. Graph A illustrates all waterbodies, while Graph B excludes lakes and rivers to better illustrate the area of remaining habitat types.
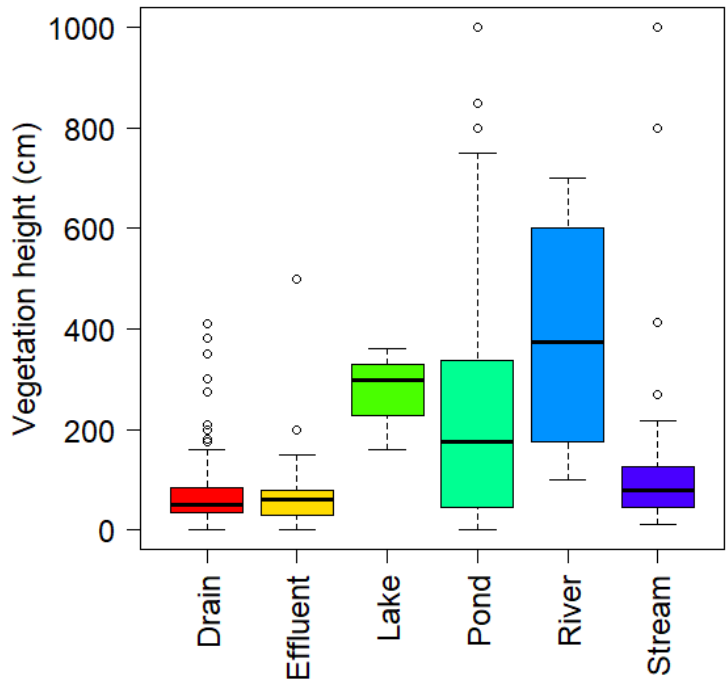
Figure 11 - Boxplot of vegetation height in relation to waterbody type, showing mean height (black line), 25-75th quantiles (coloured boxes), 95% range (whiskers) and outliers (hollow dots).
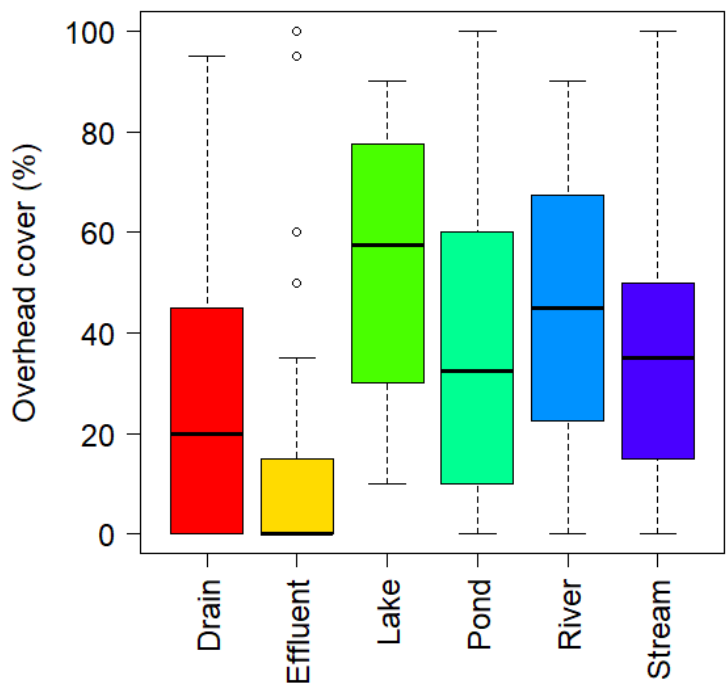
Figure 12 - Boxplot of overhead cover in relation to waterbody type, showing mean overhead cover (black line), 25-75th quantiles (coloured boxes), 95% range (whiskers) and outliers (hollow dots).
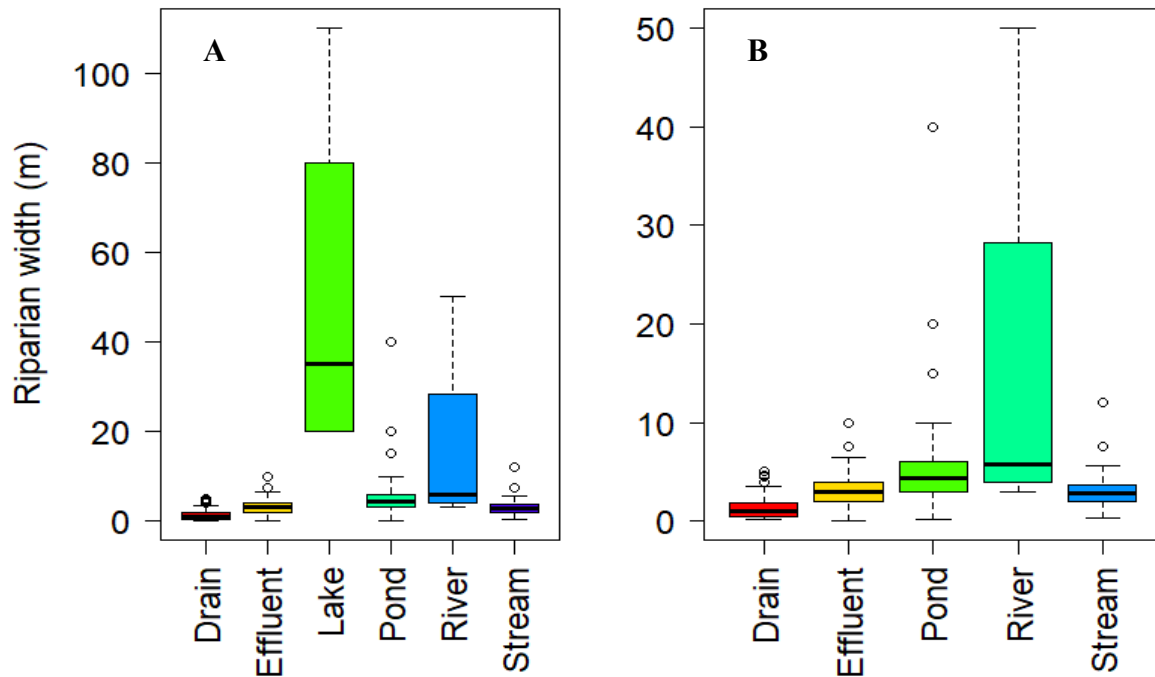
Figure 13 - Boxplot of the riparian width in relation to waterbody type, showing mean riparian width (black line), 25-75th quantiles (coloured boxes), 95% range (whiskers) and outliers (hollow dots). Graph A illustrates all waterbodies, while Graph B excludes lakes so widths of remaining habitats are better illustrated.
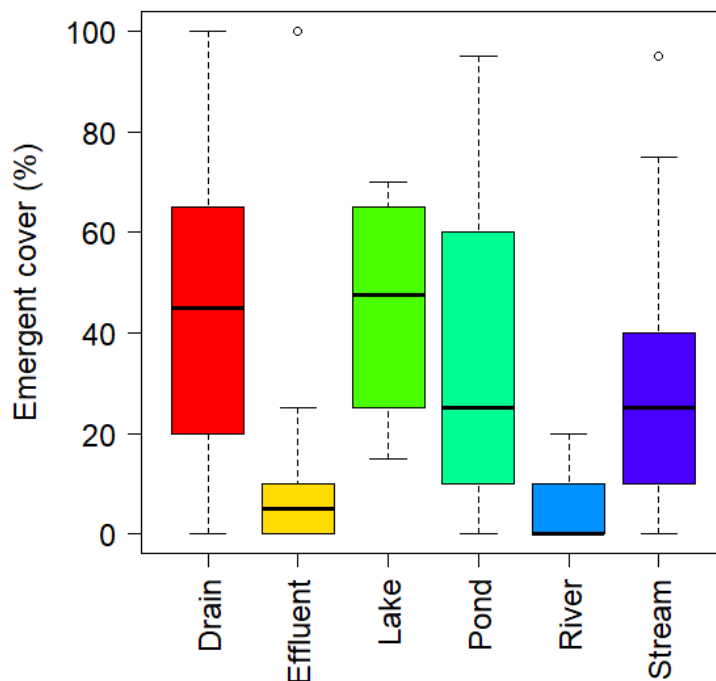
Figure 14 - Boxplot of emergent cover in relation to waterbody type, showing mean emergent cover (black line), 25-75th quantiles (coloured boxes), 95% range (whiskers) and outliers (hollow dots), as determined from 328 waterbodies that were in the nearest proximity of 2411 brood observations.

Habitat characteristics and use of local-scale habitat

We assessed habitat use at the local-scale (within 5 m^2 of the brood to represent fourth-order habitat use) based on 2,252 observations of 190 broods. The number of observations of each brood ranged from 1 – 24 ($\bar{x}$ = 11.9, SD = 5.72). Of the 2,252 brood observations, 26% occurred in paddocks, 23% occurred in or near ponds/lakes, 18% occurred in streams, creeks or rivers, 17% occurred in drains and 7% occurred in effluent ponds (Figure 15). During observations, 38% of broods were observed in rank grass, 26% in woody cover such as shrubs and trees, 25% in paddock grass, 6% in sedge, 4% in dense grass such as pampas and flax and 1% of observations had no associated vegetation (Figure 16). Mean vegetation height was 100.1 cm (range = 0 – 900, SD = 157.6, median = 40.0) and mean overhead cover was 28% (range = 0 – 100, SD = 34%, median = 10%).
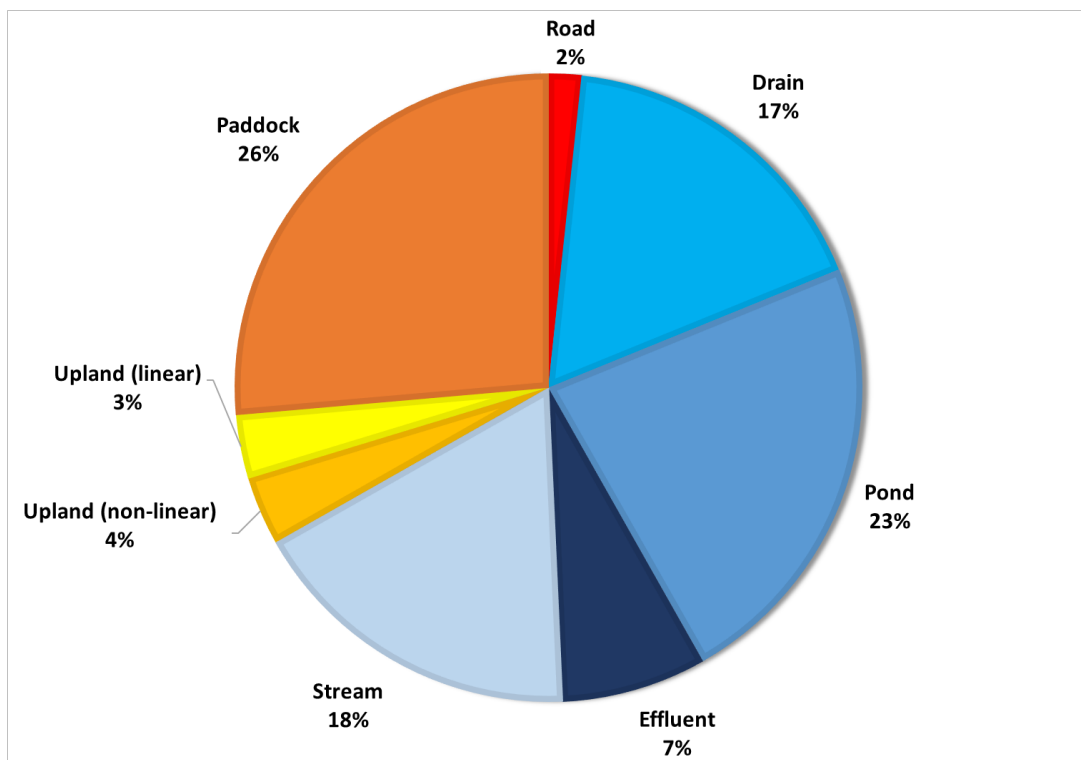
Figure 15 – Habitat types in which broods were observed during 2252 observations of 190 broods throughout Southland and Waikato, 2014–2015.
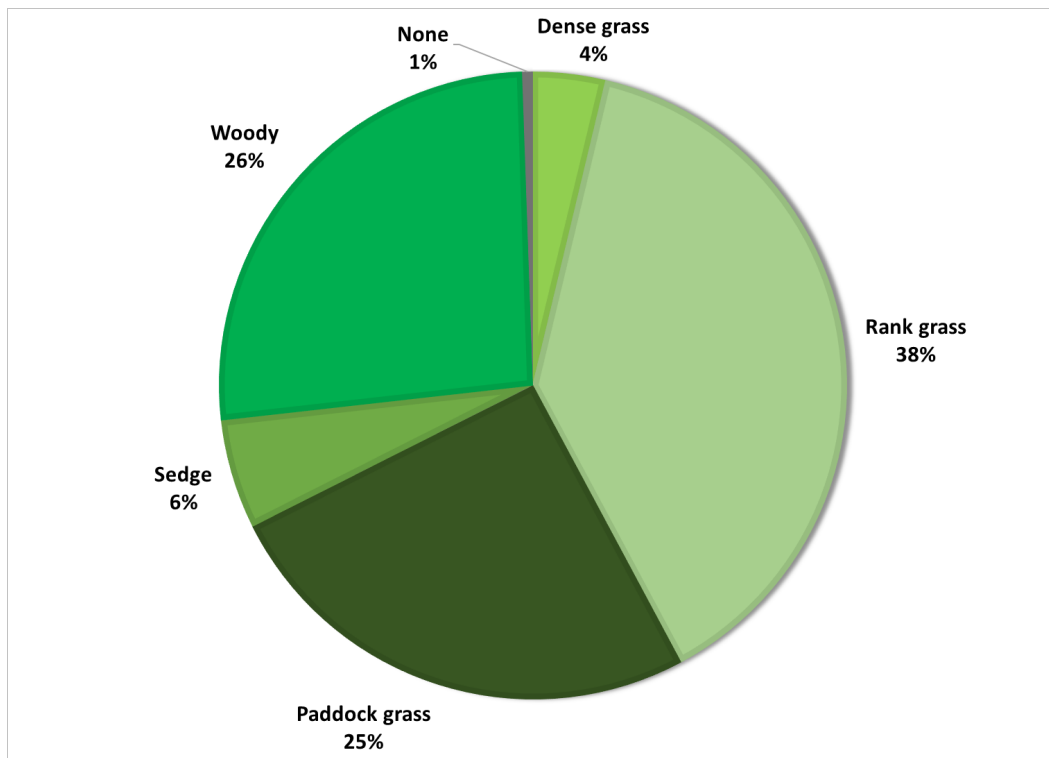
Figure 16 – The dominant vegetation types in which broods were observed during 2252 observations of 190 broods throughout Southland and Waikato, 2014–2015.

Duckling survival in relation to habitat

Our analysis included 175 radiomarked female, 190 broods (15 females had 2 broods each), 1,780 ducklings ($\bar{x}$ = 9.3 per brood, SD = 2.6, range = 2 – 15, excluding amalgamated brood of 18), and 2,243 observations. Mean number of observations per brood was 11.8 (SD = 5.7, range = 1 – 24) and the average interval between observations was 1.5 days (SD = 0.8, range = 1 – 9) for broods < 10 days old and 4.5 days (SD = 2.4, range = 1 – 24) for broods > 10 days old. Mean age of successful broods at cessation of tracking was 56.2 days (SD = 11.9, range = 30 – 83).

We assessed duckling survival using six models which varied by spatial scale and habitat selection or use (Table 4). Our first model, the 'general habitat model' focused on the primary habitats within brood buffers as well as water balance deficit. Results indicated that duckling survival was unaffected by the proportion of water and anthropogenic features within the buffer; however, duckling survival increased with a higher proportion of dense vegetation and decreased with road area (Table 8). Duckling survival was greatest when roads comprised less than 10% of the brood buffer (Figure 17A) and as the proportion of dense vegetation increased from 10% to 60%, daily duckling survival increased from 0.90 to 0.95 (Figure 17B). Duckling survival was also affected by water balance deficit such that survival exceeded 0.918 when water balance was less than zero and indicated ground saturation (i.e., as the ground got drier survival decreased; Figure 18).

Our second model, the 'habitat selection model', evaluated duckling survival in relation to habitats that broods selected at the brood-buffer scale. Results from this model indicated that duckling survival was unaffected by the proportion of sedge habitat, negatively affected by greater proportions of drains and pond and positively associated with greater areas of effluent ponds (Table 8). Duckling survival decreased below 0.90 when drains and ponds comprised > 2% and 5% of the brood buffer, respectively (Figure 19A and Figure 19B), and exceeded 0.95 when > 3% of the brood buffer contained effluent ponds (Figure 19C).

Our third model, the 'no selection model', evaluated duckling survival in relation to habitats that were unselected by broods at the 200 m brood-buffer scale. Results from this model indicated that duckling survival was unaffected by the proportion rank grass and woody cover within the brood buffer, but was positively associated with streams and hedgerows (Table 8). Duckling survival exceeded 0.95 when streams and hedgerows comprised more than 8% and 4% of the brood buffer, respectively (Figure 20A and 20B).

Our fourth model, the 'nearest waterbody model', evaluated duckling survival in relation to features of the nearest waterbody. Results from this model indicated that duckling survival was unaffected by the area, riparian width, percent of emergent vegetation, or the type of the nearest waterbody (Table 8). Duckling survival tended to decrease when broods were closest to water, however this effect was weak (Figure 21).

Our fifth model, the 'local habitat model' evaluated duckling survival in relation to habitat characteristics within 5 m^2 of the brood. Results from this model indicated that duckling survival was unaffected by habitat type and the percent of overhead cover, however duckling survival tended to decrease with vegetation height (Table 8). When vegetation height averaged 50 cm, daily survival was 0.895, but decreased to 0.888 and 0.780 as

vegetation height increased to 100 and 800 cm, respectively (Figure 21). Our final model, the 'vegetation type model' focused solely on vegetation height. Results from this model indicated that duckling survival was unaffected by the vegetation type that was reported within 5 m^2 of the brood location (Table 8).

Table 8 - Posterior mean and 95% confidence intervals for logit-scale model parameters used to evaluate duckling survival[1] for mallards in Southland and Waikato, 2014–2015.

Model	Parameter	Estimate	LCI	UCI	Fitness consequence
Model 1: General habitat	Intercept	2.360	2.269	2.493	n/a
	Brood age	0.058	0.052	0.064	n/a
	Water	-0.064	-0.124	0.003	not evident
	Roads	-0.109	-0.189	-0.022	–
	Dense cover	0.173	0.085	0.273	+
	Anthropogenic	0.026	-0.046	0.102	not evident
	Water balance	-0.079	-0.142	-0.014	+
Model 2: Habitat selection	Intercept	2.369	2.279	2.460	n/a
	Brood age	0.057	0.051	0.062	n/a
	Drain	-0.129	-0.189	-0.067	–
	Pond	-0.100	-0.163	-0.034	–
	Effluent pond	0.174	0.110	0.245	+
	Sedge	0.003	-0.057	0.067	not evident
Model 3: No selection	Intercept	2.378	2.287	2.377	n/a
	Brood age	0.057	0.051	0.063	n/a
	Stream	0.174	0.059	0.293	+
	Grass	-0.091	-0.197	0.015	not evident
	Woody cover	0.037	-0.048	0.123	not evident
	Hedgerow	0.216	0.115	0.320	+
Model 4: Nearest waterbody	Intercept	1.691	0.583	3.127	n/a
	Brood age	0.059	0.054	0.065	n/a
	Nearest water	0.044	0.002	0.088	+
	Waterbody area	-0.025	-0.174	0.126	not evident
	Riparian width	0.085	-0.110	0.284	not evident
	Emergent cover	0.031	-0.020	0.081	not evident
	Waterbody type				
	Drain	0.673	-0.782	1.793	not evident
	Pond	0.648	-0.790	1.774	not evident
	Lake	-0.388	-1.825	0.960	not evident
	River	0.975	-0. 519	1.957	not evident
	Stream	0.764	-0.682	1.880	not evident
	Effluent	0.557	-0.898	1.712	not evident

Table 8 - continued

Model	Parameter	Estimate	LCI	UCI	Fitness consequence
Model 5: Local-scale habitat characteristics	Intercept	2.371	1.075	3.832	n/a
	Brood age	0.057	0.051	0.064	n/a
	Habitat type				
	Road	-0.101	-1.602560	1.210	not evident
	Drain	1.223	-0.345	1.975	not evident
	Effluent pond	-0.383	-1.845	0.946	not evident
	Pond/lake	-0.151	-1.608	1.158	not evident
	Stream	0.276	-1.190	1.589	not evident
	Upland linear	-0.237	-1.712	1.078	not evident
	Non-linear upland	-0.348	-1.820	0.982	not evident
	Paddock	0.332	-1.134	1.655	not evident
	Vegetation height	-0.073	-0.109	-0.035	–
	Overhead cover	0.013	-0.021	0.048	not evident
Model 6: Local-scale (vegetation type)	Intercept	1.494	0.740	3.026	
	Brood age	0.057	0.052	0.063	
	Vegetation type				
	Dense grass	0.738	-0.825	1.555	not evident
	Paddock grass	1.274	-0.275	1.974	not evident
	Rank grass	0.823	-0.711	1.575	not evident
	Woody	0.826	-0.719	1.582	not evident
	Sedge	0.689	-0.863	1.506	not evident
	None	0.426	-1.146	1.336	not evident

[1] Our model structure simultaneously evaluated brood survival and duckling and brood detection. Model-specific parameter estimates and associated covariates are provided in Table 11 in Appendix 2.
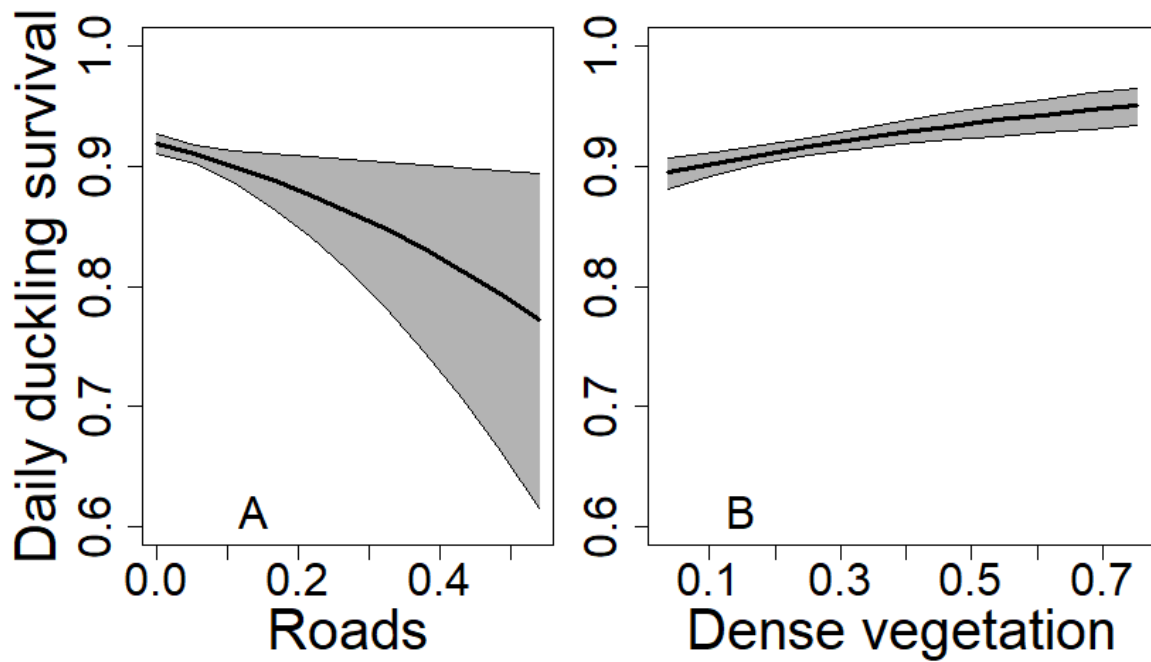
Figure 17 - Daily duckling survival in response to the proportion of A) roads and B) dense vegetation within the brood buffer of female mallards in Southland and Waikato, 2014–2015. Shaded area represents 95% confidence intervals.
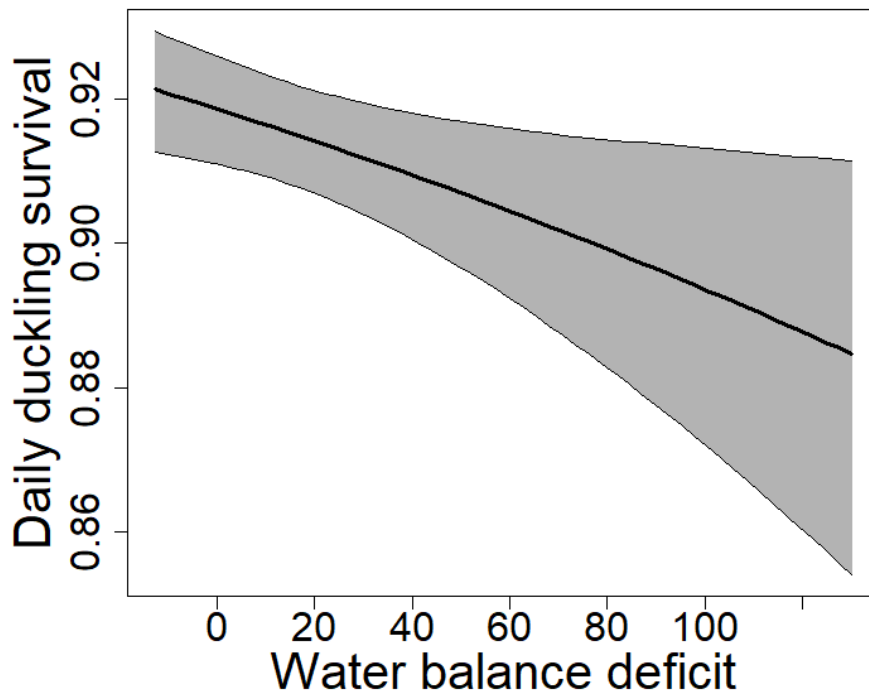
Figure 18 - Daily duckling survival in response to water balance deficit, whereby negative values indicate saturation and presumably greater areas of ephemeral wetlands. Shaded area represents 95% confidence intervals.
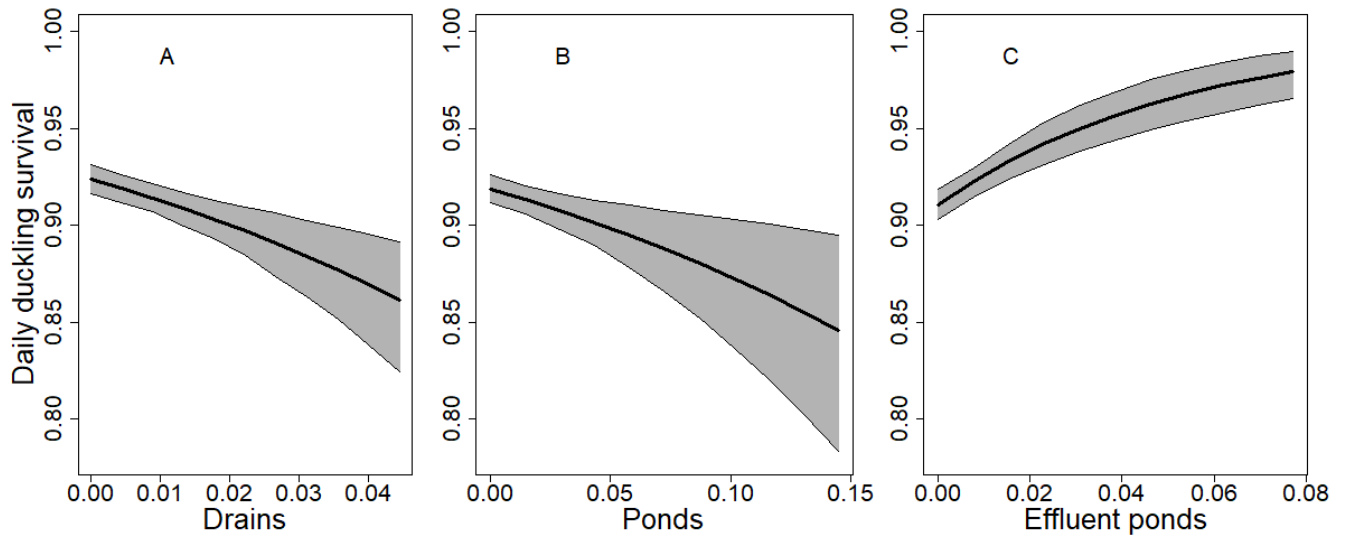
Figure 19 - Daily duckling survival in response to the proportion of A) drains, B) ponds (including natural and man-made, but excluding effluent), and C) effluent ponds within the brood buffer of female mallards in Southland and Waikato, 2014-2015. Shaded area represents 95% confidence intervals.
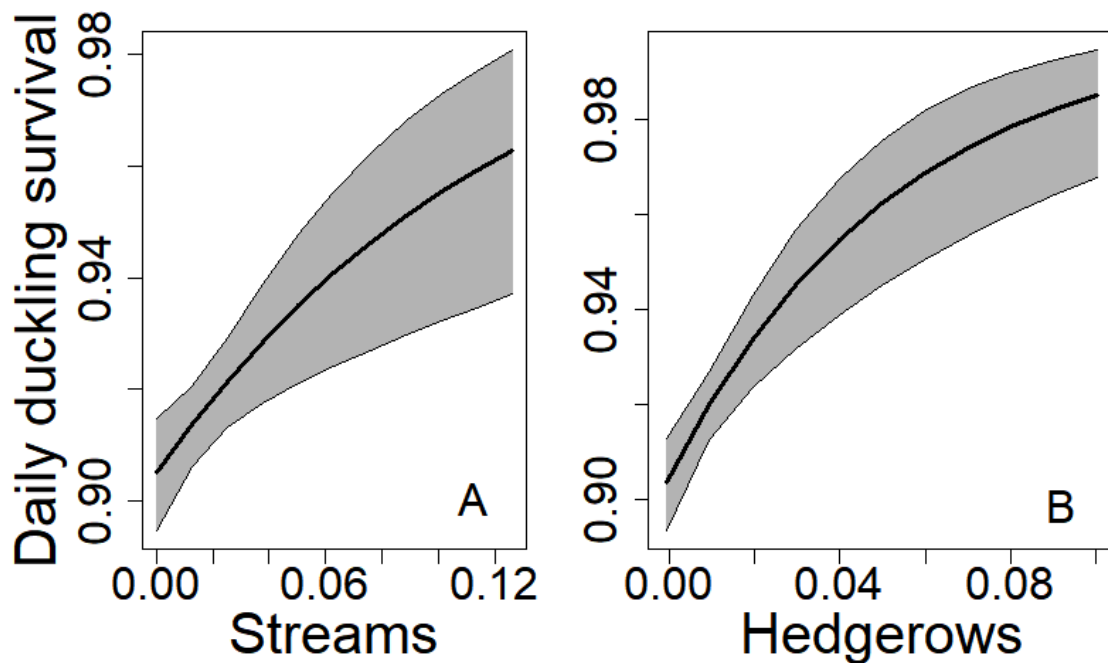
Figure 20 - Daily duckling survival in response to the proportion of A) Streams and B) Hedgerows within the brood buffer of female mallards in Southland and Waikato, 2014-2015. Shaded area represents 95% confidence intervals.
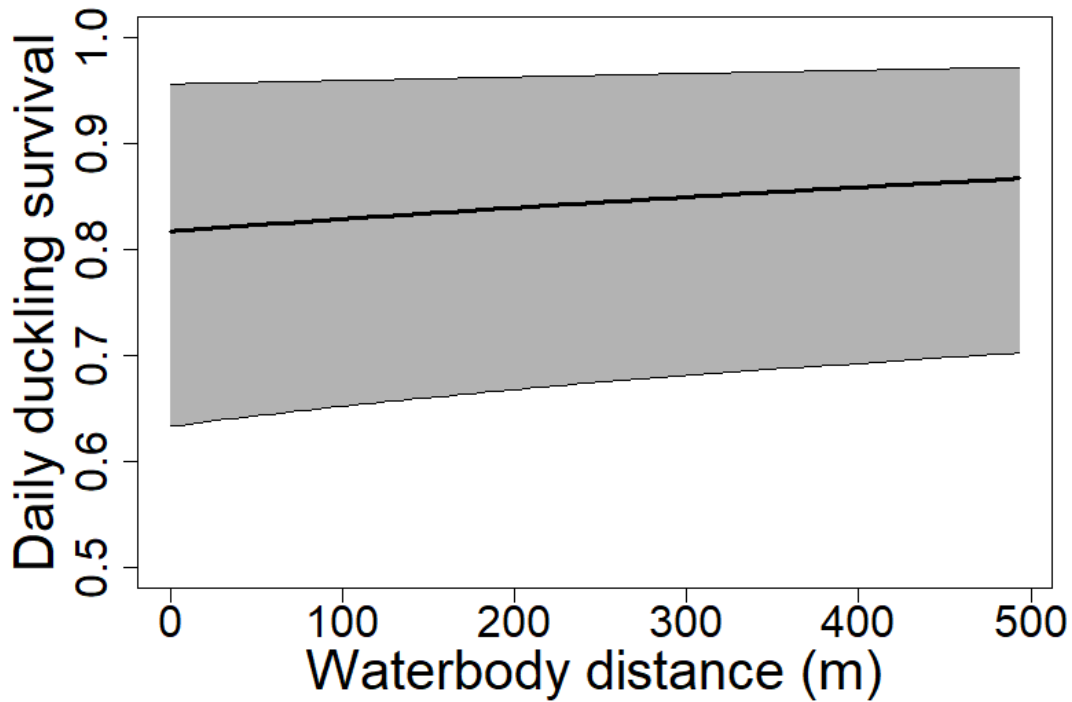
Figure 21 - Daily duckling survival of female mallards in Southland and Waikato, 2014-2015 in response to the distance to the nearest waterbody. Shaded area represents 95% confidence intervals.
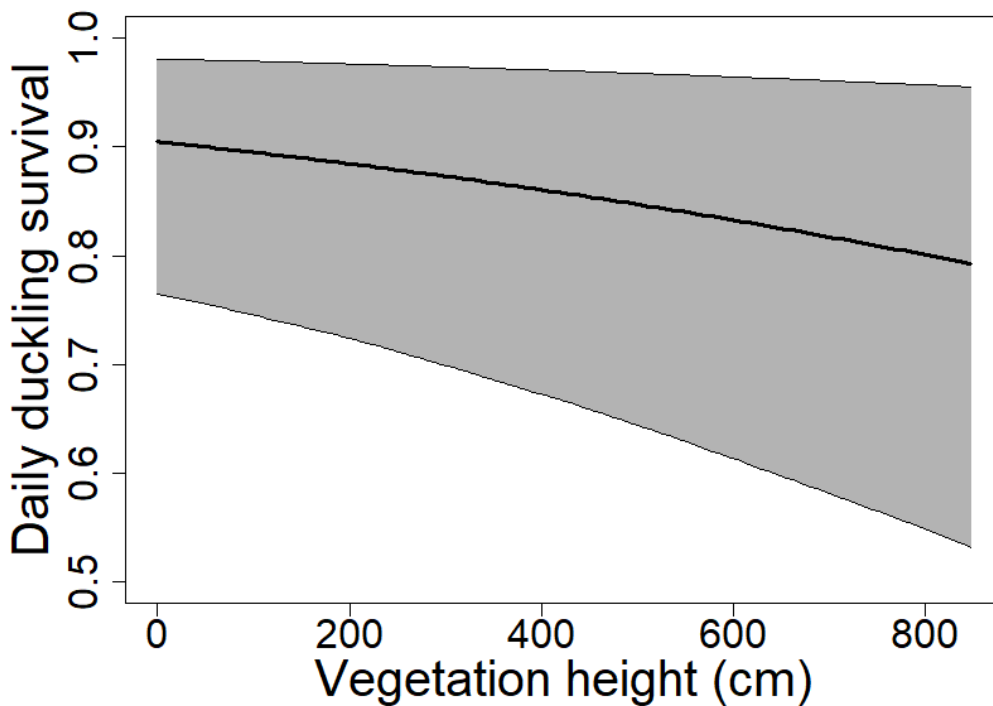
Figure 22 - Daily duckling survival in response to vegetation height at the local-scale (within 5 m^2), for mallard broods in Southland and Waikato, 2014-2015. Shaded area represents 95% confidence intervals.

DISCUSSION

Our results suggest that mallards in NZ exhibit both adaptive and maladaptive patterns of second-order habitat selection (Table 9). Mallards that selected brood-sites with greater proportions of effluent ponds and streams experienced higher duckling survival; suggesting that, at the brood-buffer or home-range scale, greater areas of effluent ponds and streams throughout the landscape are beneficial and confer reproductive benefits. Although road habitat was associated with lower duckling survival, broods appeared to neither select nor avoid areas with higher proportions of roads, indicating that this pattern of habitat selection may also be adaptive.

Mallards also exhibited maladaptive habitat choices which led to both ecological and perceptual traps. Ecological traps occur when animals select habitats that are associated with lower fitness, and our analysis illustrated that mallards selected areas with abundant drain and pond habitats despite lower duckling survival associated with higher proportions of these habitat types. Perceptual traps occur when animals avoid habitats that result in higher fitness. Although we found no evidence of avoidance, our results indicated that mallards neither selected nor avoided brood-rearing areas that had greater areas of hedgerows, yet duckling survival was positively associated with this habitat.

Table 9 - Patterns of habitat selection and associated fitness consequences and outcomes of female mallards in Southland and Waikato, 2014–2015, as determined from a 200-m radius brood buffer derived from brood location data and assumed brood routes.

Habitat type	Selection	Fitness consequence	Outcome
Water	+	not evident	Potential ecological trap
Roads	not evident	–	Adaptive avoidance
Dense cover	not evident	+	Perceptual trap
Anthropogenic	not evident	not evident	Neutral
Drain	+	–	Ecological trap
Pond/lake	+	–	Ecological trap
Stream	+	+	Adaptive selection
Effluent pond	+	+	Adaptive selection
Grass	not evident	not evident	Neutral
Woody cover	not evident	not evident	Neutral
Hedgerow	not evident	+	Perceptual trap
Sedge	+	not evident	Potential ecological trap

Ponds, effluent ponds, drains and streams

At the 200 m scale, females tended to select brood-rearing areas with greater areas of drains, ponds, effluent ponds, and to a lesser extent streams. However, only effluent ponds and streams conferred fitness benefits. At smaller, local-scales, broods tended to use ponds, streams and drains more often than effluent ponds, yet duckling survival was unrelated to habitat type at the local scale. These results suggest that at larger spatial scales, greater areas of effluent ponds and streams throughout the landscape may benefit ducklings, while greater

areas of ponds and drains may lead to ecological traps. Differences in habitat features outside of the scope of this study such as predator and invertebrate communities associated with different waterbody types, and/or nutrients and pollution may explain these results. For instance, duckling survival decreased with vegetation height at local-scales (Figure 22). Forested areas and trees provide hunting perches for avian predator and cover for mammalian predators that have been linked to lower duckling survival rates (Simpson et al. 2007, Amundson & Arnold 2011, Bloom et al. 2013, Garrick et al. 2017). Compared to effluent ponds, ponds and lakes tended to have taller vegetation, greater overhead cover and wider riparian margins (Figure 11, Figure 12 & Figure 13, respectively). Possibly, alternative prey may be available or predator abundance may be lower in brood-rearing areas that have greater areas of effluent ponds (and presumably fewer trees and shrubs), whereas areas with abundant ponds and lakes (and more trees and shrubs), may harbour higher densities of duckling predators and/or less alternative prey sources. This may explain the positive association between effluent ponds and duckling survival rates observed here, as well as higher rates of nest survival observed in a concurrent study (Cosgrove et al. 2015).

Understanding predator and prey densities of different waterbodies, in association with vegetation type/height, could aid the development of management recommendations for desirable planting regimes and could yield important insights into why ducklings survive better in certain waterbodies than others. However, streams also had taller vegetation, and duckling survival increased when there were higher proportions of streams within the brood-rearing area, so this hypothesis alone does not fully explain our results and suggests that additional factors also influence duckling survival. For example, the linearity of drains and relatively low vegetation cover may create efficient foraging corridor for hawks (Dugger et al. 2016). On several occasions investigators reported seeing hawks flying low over drains, presumably searching for ducklings, and observers witness predation of duckling by both pukekos and hawks during the study. Even though trees and woody habitats along ponds and streams might harbour mammalian predators, the additional overhead cover could benefit ducklings by providing hiding places and refugia from avian predators. Thus, there may be a trade-off between avoiding mammals that inhabit tall vegetation around ponds and streams, while having access to enough overhead cover to avoid hawks.

Garrick et al. (2017) postulated that anthropogenic areas may have greater predator abundance. Possibly, areas around milking sheds and associated effluent ponds have higher abundances of mice and rats, which may serve as alternative food sources to duckling predators such as cats, ferrets and stoats. As such, broods that have higher proportions of effluent ponds within their brood-rearing areas may benefit from prey dilution, either from other broods or alternative food sources. On numerous occasions, several broods were observed on the same effluent pond together and observers reported females fighting for space, indicating that these habitats are certainly preferred, but the attributes that attract broods to effluent ponds remains poorly understood. Effluent ponds are high nutrient environments, but often have rich invertebrate assemblages. In the Waikato they represent some of the few aquatic environments which are pest fish free due to the lack of connectivity with natural waterways. In the Waikato, and to a lesser extent in Southland, lakes, wetlands and drains are often severely degraded with high sediment loads. Many waterways have

'flipped' with complete collapse of macrophytes and have turned into soft bottomed algal dominated states. These degraded waterways also tend to have depauperate invertebrate communities and this may also explain why brood areas with more effluent ponds led to improved duckling survival. Increasingly, effluent ponds are moving away from traditional earth bund designs and becoming lined with plastic polymers to avoid leaching. This study did not differentiate between natural and lined ponds, but the majority had not been lined at the time of the project. Unless plastic lined ponds have ladders (or other escape mechanisms) put in place, ducklings are unable to exit and often perish. If the trend towards lined effluent ponds continues without consideration for wildlife escape mechanisms it is likely that survival rates of ducklings using these environments will reduce.

The morphology and water quality of streams and drains may differ vastly and could explain the differences in duckling survival rates. Wider riparian margins associated with streams likely filters agricultural run-off and reduces sediment loads. For instance, phosphorous is prevalent in NZ drains (Nguyen & Sukias 2001) and has been linked to decreased duckling growth (Sparling 1990). Gibb (2018) analysed blood samples of females used in this study, as well as additional samples of mallards collected in Southland and Waikato and quantified liver concentrations of cadmium, cooper and lead. Overall, birds from Southland and adult birds had higher cadmium levels ($\bar{x}_{Southland} = 0.84$, $\bar{x}_{Waikato} = 0.65$, $\bar{x}_{Adult} = 0.94$, $\bar{x}_{Juvenile} = 0.55$), birds in Waikato had higher volumes of lead ($\bar{x}_{Southland} = 0.25$, $\bar{x}_{Waikato} = 0.55$), and males had higher levels of both cooper ($\bar{x}_{Male} = 100.8$, $\bar{x}_{Female} = 55.9$) and lead ($\bar{x}_{Male} = 0.42$, $\bar{x}_{Female} = 0.35$) (Gibb 2018). A significant number of the individuals showed exposure levels that are likely to impact reproductive biology of mallards (Gibb 2018). These heavy metals can also have profound influences on ducklings. For instance, black duck (*Anas rubripes*) ducklings that were fed high cadmium diets responded differently to fright stimulus by travelling less distances (Heinz et al. 1983); thus, high cadmium levels could make ducklings more prone to predation. Additionally, high lead-levels have been shown to decrease growth of mallard ducklings, affect balance and mobility, reduce time spent swimming and bathing, impact cellular immune responses and, in severe cases, lead to duckling death (Douglas-Stroebel et al. 2005, Vallverdú-Coll et al. 2015).

Macroinvertebrate communities could also be influenced by heavy metals or pest-fish and potential differences in macroinvertebrate communities among the various waterbody types may explain habitat selection and/or duckling survival. Higher invertebrate densities are positively related to duckling growth and subsequent survival (Dzus & Clark 1997, Cox et al. 1998) and effluent ponds in the Waikato possibly have a greater abundance of invertebrates due to the absence of pest-fish such as mosquitofish (*Gambusia affinis*), catfish (*Ameiurus nebulosus*), rudd (*Scardinius erythrophtalmus*), goldfish (*Carassius auratus*) and koi carp (*Cyprinus carpio*), which are associated with decreased macroinvertebrate abundance and diversity (Leyse et al. 2003, Garrett-Walker 2014). Drains may have lower invertebrate biomass, presumably due to increased contamination, spraying and/or cleaning.

Water balance deficit

Garrick et al. (2017) found that duckling survival in Southland increased with the presence of ephemeral water. We analysed water balance deficit and found that duckling survival was highest when the deficit was below zero (Figure 18). This suggests that duckling survival was higher when there was a surplus of water and the ground was saturated, which presumably creates ephemeral wetlands in flooded paddocks. Research in Puerto Rico found that the survival of white-checked pintail ducklings (*Anas bahamensis*) increased with precipitation, which likely increased cover and food access amid interspersed vegetation in flooded areas (Davis et al. 2017). A similar phenomenon likely occurs in NZ and would explain why broods had an affinity to paddocks.

Water balance deficit increased with seasonal progression (Figure 23), however duckling survival does not increase with season or hatch date but instead is consistent throughout the season (Garrick et al. 2017, Sheppard 2018). This consistency is possibly due to a milder climate or more stable food sources in New Zealand, compared to North America where survival is related to hatch date (Garrick et al. 2017). Interval-specific water balance, as analysed here, measures the average water deficit during each brood-interval (i.e., time between each consecutive observation) for each brood. Thus, deficit values are different for each brood, at each age, because brood observations occurred when required (i.e., different broods were observed on different days and not all intervals are equal length). The positive association between interval-specific water balance deficit and duckling survival suggests that managers may be able to use water balance to predict productivity.
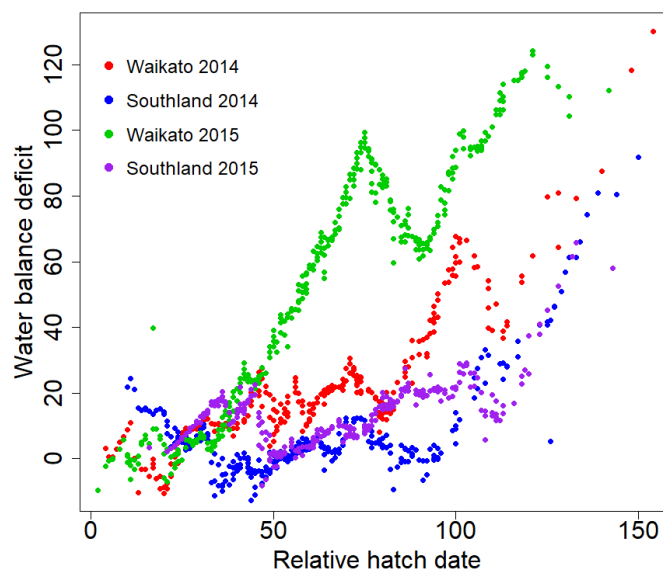

Figure 23 - Water balance deficit in relation to relative hatch date (1 = 1 September; 150 = 29 January) for each site-year

Roads

At the brood-site scale, broods appeared to neither select nor avoid roads, yet roads were associated with reduced duckling survival, indicating that this pattern of habitat selection may

also be adaptive. At the local scale, less than 2% of brood observations occurred near roads and these were likely in instances of broods leaving the nest-site. We know broods cross roads because on several occasions consecutive observations were conducted on the same brood but at different waterbodies on different sides of roads and motorways (J. Sheppard, pers. observ.). Additionally, newly hatched broods just leaving the nest often start their lives along roadsides. Roads and associated vehicles likely pose a threat to duckling survival and could explain why duckling survival decreased when there were higher proportions of roads within the brood buffer. Nesting mallards select nest-sites closer to roads and nest survival is twice as high along roadsides than adjacent to aquatic habitats which is associated with the amount of dense nesting vegetation associated with these areas (Sheppard 2018). There is likely a trade-off for mallards closer to roads in safer nest areas at the cost of having to contend with traffic and anthropogenic threats to ducklings immediately following hatch., Because brood use of roads is minimal and broods do not select brood-rearing areas with higher proportions of roads, roadside habitat is relatively unimportant to duckling survival.

Dense cover, hedgerows, sedges, emergent cover and overhead cover

We defined dense cover as rank grass, hedgerows, shelterbelts, and woody cover (trees and shrubs). At the 200 m brood-buffer scale, broods did not select dense cover, yet duckling survival increased with greater proportions of dense cover within the brood buffer (Table 9, Figure 17B). Nesting mallards also selected nest-sites that had higher proportions of dense cover within a 200 m nest buffer, but nest survival appeared unaffected (Sheppard 2018). Conversely, Garrick et al. (2017) found duckling survival decreased with a greater proportion of dense cover, however their analysis only focused on broods from Southland in 2014, and their brood buffers were 50 m radius as opposed to our 200 m radius. Stage-specific habitat-selection trade-offs between nesting and brood-rearing habitats could explain the incongruencies among selection of dense cover and associated survival of nests and duckling.

When we analysed the separate components of dense cover, we found no selection for rank grass, woody cover, or hedgerows/shelterbelts, however our results indicated that duckling survival increased when buffers contained more hedgerow area (Table 9, Figure 20B). Hedgerows were often located along roadsides ($r = 0.63$, df = 188, p < 0.001) or drains ($r = 0.08$, df = 188, p = 0.27). Given the high correlation between roadsides and hedgerows and reduced survival associated with roads and vegetation height, we would expect that hedgerows would also be related to lower duckling survival rates; however, this was not the case. Perhaps the narrowness of the row and the densely, interlocked branches creates inferior habitat for duckling predators; thus, areas with higher proportions of hedgerows possibly have fewer predators. Nevertheless, only 3% of brood observations occurred in, or near, hedgerows, so this habitat type seems relatively unimportant to broods when compared to aquatic habitats and paddocks.

Broods also selected brood buffers that had higher proportion of sedge/rush habitat, despite no relationship between sedge and duckling survival. The proportion of sedge habitat was weakly correlated to the proportion of ponds ($r = 0.20$, df = 188, p = 0.007) and unrelated to the proportion of effluent ponds ($r = -0.006$, df = 188, p = 0.93), streams ($r = 0.07$, df = 188, p = 0.29) or drains ($r = 0.11$, df = 188, p = 0.15). Sedges, rushes and other

aquatic vegetation provide emergent cover, which benefits ducklings by offering food, escape cover from predators, and shelter during rain events which may provide better thermoregulatory conditions (Simpson et al. 2007, Stafford and Pearse 2007). Our results indicated that duckling survival was unaffected by the percent of emergent cover at the nearest waterbody, but McDougall et al. (2018) reported that broods in the Bay of Plenty were observed more often in drains that had more emergent cover/floating vegetation. Therefore, we recommend that managers encourage planting and restoration of sedge and other emergent vegetation to attract broods to high-quality waterbodies (i.e., areas known to have enough food and reduced predator numbers). Attracting broods to those sites could ultimately improve mallard productivity, but caution should be taken to avoid attracting broods to potential ecological traps.

We found no relation between overhead cover and duckling survival, however McDougall et al. (2018) reported that in drains, brood presence increased when there were a small number of overhanging trees and shrubs present along the drain. The relationship between overhead cover and duckling survival may be quadratic and too few or too many trees are detrimental, but some trees are beneficial.

Management recommendations

Ecological traps arise when anthropogenic changes in the environment disrupt the cues that signal good quality habitat or when elements in the environment mimic traditional cues for habitat choices (Schlaepfer et al. 2002).We found that drains and ponds (at the home-range/brood-rearing area scale) are ecological traps to mallard duckling survival (Table 9). Mallards selected brood-rearing areas that have higher areas of drains and ponds, and our data indicate that broods readily use these habitat types (Figure 15). Possibly, drains and ponds have fewer or lower-quality food sources, higher predator communities, or poor water quality and could explain the low duckling survival associated with increasing areas of these habitats. Drains, and aquatic habitats in general, were also associated with lower nest survival (Sheppard 2018), suggesting that predators could be the main factor attributing to lower survival rates.

Adaptive selection occurs when animals select habitats that are associated with improved survival rates. In this study, duckling survival increased when broods selected brood-rearing habitats with higher proportions of effluent ponds, streams and hedgerows. These habitats are possibly associated with lower predator abundance or increased food sources. Nevertheless, any effort to protect or promote these habitats may improve duckling survival and ultimately increase mallard productivity.

In conclusion, we recommend the following actions should be taken:

1. Streams and effluent ponds provided adaptive brood-rearing habitat. In instances where landowners have effluent ponds on their land, educating them about the importance of effluent ponds and encouraging those with lined ponds to install escape mechanisms may benefit duckling survival. Additionally, maintaining and enhancing streams with dense vegetation may also improve survival rates. Finally, investigating which habitat characteristics of streams and effluent ponds attributes to higher duckling survival may yield important insights for restoration programs of other waterbody types.

2. Brood-rearing females selected buffers with higher proportions of sedge habitat. To attract birds to productive wetlands, we suggest that habitat managers increase the area of sedge/rush habitat. Concurrently, managers should discourage abundant planting of tall vegetation (i.e., trees and shrubs) and take caution to ensure planting of sedge habitat does not lead to ecological traps by attracting broods to low quality wetlands with high numbers of predators or low food sources. In conjunction with sedge/rush planting, predator trapping could be encouraged although further studies may be warranted to determine both the impact of different predator guilds on duckling survival and the efficacy of any control prior to investing heavily in this management tool.

3. Hedgerows were positively associated with duckling survival. Possibly, the thickness of hedge species creates unfavourable habitat for duckling predators)i.e., hedges limit the ability of predators to track along edges of waterbodies) and may explain why duckling survival was higher when there were greater proportions of hedgerows within the brood buffers. We recommend managers discourage the removal of hedgerows and promote or enhance planting of dense hedge species around or near important waterbodies. Based on our results, maintaining hedgerows or hedge species in close proximity to streams and effluent ponds in particular, may benefit duckling survival.

4. Water balance deficit is associated with daily duckling survival, so we recommend that managers direct efforts to prevent the removal of sub-surface drainage during peak brood-rearing and promote the creation of seasonal or ephemeral wetlands. Water deficit may potentially be used as a tool to predict duckling survival and feed back into population models. Future research could include a multi-year study to:
   a. identify the relationship between water deficit and ephemeral wetlands
   b. conduct pair: brood ratios to prior to and during the breeding season which can be used to determine relative productivity and predict population projections (Cowardin & Blohm 1992, Pagano et al. 2014). If pair: brood ratios correspond to water balance deficit, then overtime, managers may be able to use weather data during spring and summer in conjunction with other data e.g. survival rates from banding to forecast a population response.

5. Sheppard (2018) found that productivity of mallards in New Zealand was limited by both duckling and female survival. Any initiative that can protect ducklings or enhance growth

and survival will ultimately improve mallard population growth. We recommend that managers continue to direct efforts to enhance habitat characteristics that have been linked to improved duckling survival or abundance, as determined from this study and associated studies throughout NZ. In particular, managers should focus efforts on: i) increasing riparian margins; ii) advocating for the retention and protection of wetlands iii) restoring ponds and wetlands; iv) identifying and conserving waterbodies where pest-fish have not established; v) identifying and conserving ephemeral wetlands, and vi) encouraging landowners to manage and control predators.

6. Initiatives that protect females will also enhance productivity. Targeted predator control particularly during key nesting periods and encouraging hunters to shoot fewer hens may improve female survival and ultimately increase duckling densities throughout the landscape.

7. To further improve management recommendations, we also suggest that managers consider conducting additional research to better understand predator and invertebrate communities of various waterbody types. For instance, designing a program to remove predators around drains and ponds and comparing predator communities and duckling densities between trapped and non-trapped areas could provide essential information about the efficiency of predator trapping (sensu Amundson et al. 2013). Understanding which food sources are associated with each waterbody may also provide additional opportunities to enhance duckling survival. Waterbodies with low invertebrate biomass or abundance could undergo faunal recruitment and restoration by inoculating or stocking low-quality waterbodies with vegetation and sediment from high-quality ponds or with invertebrates from nearby waterbodies (Brown et al. 1997, Brady et al. 2002).

Literature Cited

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

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

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

Block, W.M. & L.A. Brennan. 1993. The habitat concept in ornithology: theory and applications. *In* D.M. Power (ed.). Current Ornithology, Volume 11. Plenum Press, new York.

Bloom, P.M., R.G. Clark, D.W. Howerter & L.M. Armstrong. 2011. Landscape-level correlates of mallard duckling survival: implications for conservation programs. Journal of Wildlife Management 76: 813-823.

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

Brady, V.J., B.J. Cardinale, J.P. Gathman & T.M. Burton. 2002. Does facilitation of faunal recruitment benefit ecosystem restoration? An experimental study of invertebrate assemblages in wetland mesocosms. Restoration Ecology 10: 617-626.

Brown, S.C. K. Smith & D. Batzer. 1997. Macroinvertebrate responses to wetland restoration in northern New York. Environmental Entomology 26: 1016-1024.

Calgene, C. 2006. The package 'adehabitat' for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197: 516-519.

Clark R.G. & D. Shutler. 1999. Avian habitat selection: pattern from process in nest-site use by ducks? Ecology 80: 272-287.

Cosgrove, J., C.L. Amundson, J.L. Sheppard & D. Klee. 2015. Effects of habitat fragmentation on nest survival of New Zealand mallards in the Auckland/Waikato Fish and Game Region. Unpubl. technical report, Auckland/Waikato Fish and Game Council, Hamilton, NZ.

Cowardin, L.M. & R.J. Blohm. 1992. Breeding population inventories and measures of recruitment. Pages 423-445 *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. University of Minnesota Press, Minneapolis.

Cox, R.R., M.A. Hanson, C.C. Roy, N.H. Euliss, D.H. Johnson & M.G. Bulter. 1998. Mallard duckling growth and survival in relation to aquatic invertebrates. Journal of Wildlife Management 62: 124-133.

Davis, J.B., F.J. Vilella, J.D. Lancaster, M. Lopez-Flores, R.M. Kaminkski & J.A. Cruz-Burgos. 2017. White-cheecked pintail duckling survival and brood survival across wetland types at Humancao Nature Reserve, Puerto Rico. Condor 119: 308-320.

Douglas-Stroebel, E.K., G.L. Brewer & D.J. Hoffman. 2005. Effects of lead-contaminated sediment and nutrition on mallard duckling behaviour and growth. Journal of Toxicology and Environmental Health 68 (2).

Dugger, B.D., J.M. Coluccy, K.M. Dugger, T.T. Fox, D. Kraege & M.J. Petrie. 2016. Population dynamics of mallards breeding in eastern Washington. Journal of Wildlife Management 80: 500-509.

Dzus, E.J. & R.G. Clark. 1997. Overland travel, food abundance, and wetland use by mallards: relationships with offspring survival . Wilson Bulletin 109: 504-515.

FME Desktop. 2015. Safe Software Inc. Surrey, British Columbia, Canada. *Available at*: https://www.safe.com/fme/fme-desktop/

Garrett-Walker, J. 2014. The ecology of constructed ponds on the lower Waikato River floodplain: implications for waterfowl management. Unpubl. MSc. thesis, University of Waikato, Hamilton, NZ.

Garrick, E. 2015. Duckling survival and habitat selection of brood-rearing mallard females in Southland, New Zealand. Unpubl. MSc. thesis, University of Otago, Dunedin, NZ.

Garrick, E., C.L. Amundson, and P. J. Seddon. 2017. Duckling survival of mallards in Southland, New Zealand. Journal of Wildlife Management 81: 858-867.

Gelman, A. & D.B. Rubin. 1992. Inference from iterative simulation using multiple sequences. Statistical Science 7: 457-472.

Gendron, M. & R.G. Clark. 2000. Factors affecting brood abandonment in gadwalls (*Anas strepera*). Canadian Journal of Zoology 78: 327-331.

Gibb, K. 2018. Heavy metal concentrations in mallards in New Zealand. Unpubl. MSc. thesis, Massey University, Palmerston North, NZ.

Heinz, G.H., S.D. Haseltine & L.Sileo. 1983. Altered avoidance behaviour of young black ducks fed cadmium. Environmental Toxicology and Chemistry 2 (4).

Hutto, R.L 1985. Habitat selection by nonbreeding migratory land birds. *In* M.L. Cody (Ed.), Habitat Selection in Birds. Academic Press, New York.

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

Jones, J. 2001. Habitat selection studies in avian ecology: a critical review. Auk 118: 557-562.

Kellner, K. 2015. jagsUI: a wrapper around 'rjags' to streamline 'JAGS' analyses. R package version 1.3.7. http://CRAN.R-project.org/package=jagUI.

Kenward, R. 1987. Wildlife radio tagging: equipment, field techniques, and data analysis. Academic Press, New York.

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

Levins, R. 1968. Evolution in changing environments. Princeton University Press, New Jersey.

Leyse, K.E., S.P. Lawler & T. strange. 2003. Effects of an alien fish, *Gambusia affinis*, on an endemic California fairy shrimp, *Linderiella occidentalis*: implications for conservation of diversity in fishless waters. Biological Conservation 118: 57-65.

Lukacs, P.M., V.J. Dreitz, F.L. Knopf & K.P. Burnham. 2004. Estimating survival probabilities of unmarked dependent young when detection is imperfect. Condor 106: 926-931.

Malik, P., R. Hegedüs, G. Kriska, S. Åkesson, B. Robertson & G. Horváth. 2010. Asphalt surfaces as ecological traps for water-seeking polarotactic insects: how can the polarized light pollution of asphalt surfaces be reduced? *In:* Asphaltenes: Characterization, Properties and Applications (p. 81-119). Nova Science Publishers Inc.

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

McDougall, M., B. Nieuwboer & A. Garrick. 2018. Can management regime, vegetative, and morphological characteristics of drains in the Bay of Plenty explain the presence of mallards and their broods? Unpubl. technical report, Eastern Fish and Game Council, Rotorua, NZ.

Nguygen L. & J. Sukias. 2001. Phosphorus fractions and retention in drainage ditch sediments receiving surface runoff and subsurface drainage from agricultural catchments in the North Island, New Zealand. Agriculture Ecosystems and Environment 92: 49-69.

Orians, G.H. 1980. Habitat selection: general theory and applications to human behaviour. *In*: J.S. Lockwood (Ed.), The Evolution of Human Social Behaviour. Elsevier, New York.

Pagano, A.M., C.L. Amundson, M.R. Pieron, T.W. Arnold & T.C. Kimmel. 2014. Using sightability-adjusted brood-pair ratios to estimate waterfowl productivity. Wildlife Society Bulletin 38: 566-573.

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

Patten, M.A. & J.F. Kelly. 2010. Habitat selection and the perceptual trap. Ecological Applications 20: 2148-2156.

Picman, J. & L.M. Schriml. 1994. A camera study of temporal patterns of nest predation in different habitats. Wilson Bulletin 106: 456-465.

Plummer, M. 2003. JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. *In:* Proceedings of the 3rd international workshop on distributed statistical computing. Vienna, Austria.

Pulliman, H.R. 1996. Sources and sinks: empirical evidence and population consequences. *In*: E.O. Jr. Rhodes, Chesser R.K. & Smith, M.R. (Eds.), Population Dynamics in Ecological Space and Time. University of Chicago Press, Chicago.

R Core Team. 2015. R: a language and environment for statistical computing. Vienna: R Foundation in Statistical Computing. *Available at* https://www.R-project.org/.

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

Schlaepfer, M., M.C. Runge & P.W. Sherman. 2002. Ecological and evolutionary traps. TRENDS in Ecology and Evolution 17: 474-480.

Sheppard, J.L., Arnold, T.W., Amundson, C.L. & Klee, D. 2017. Effects of surgically implanted transmitters on reproduction and survival in Mallards. Wildl. Soc. Bull. 41: 597–604.

Sheppard, J.L. 2018. Breeding ecology and productivity of Mallards and Mallard-grey Duck Hybrids in New Zealand. Unpubl. PhD Dissertation, University of Auckland, Auckland, NZ.

Sheppard, J.L. 2018*b*. Brood habitat selection and use: deliverable 1: a summary of available habitats and expected outcomes. Unpubl. short report, New Zealand Fish and Game Council, Wellington.

Simpson, J.W., T. Yerkes, T.D. Nudds & B.D. Smith. 2004. Effects of habitat on mallard duckling survival in the Great Lakes Region. Journal of Wildlife Management 71: 1885-1891.

Sparling, D.W. 1990. Acid precipitation and food quality: inhibition of growth and survival in black ducks and mallards by dietary aluminium, calcium, and phosphorus. Archives of Environmental Contamination and Toxicology 19: 457-463.

Stafford, J.D. & A.T. Pearse. 2007. Survival of radio-marked mallard ducklings in South Dakota. Wilson Journal of Ornithology 119: 585-591.

Vallverdú-Coll, N., A. López-Antia, M. Martinez-Haro, M.E. Ortiz-Santaliestra & R. Mateo. 2015. Altered immune response in mallard ducklings exposed to lead through maternal tranfer in the wild. Environmental Pollution 205: 350-356.

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

Appendix 1 - Data Recorded from Brood Observations

During brood observations, we collected habitat information within a 5 m² area of the brood. Information about each habitat characteristic, as extracted from the raw brood data, was previously described in the first deliverable of this project (Sheppard 2018*b*). For convenience, we have repeated that information here. However, please note this does not represent the true values used in this analysis; the data has since been cleaned up, some missing values have been inferred or extrapolated, and some erroneous brood observations were removed.

Habitat type

Variable type:	Categorical
Number of categories:	14
Observations with available information:	2402
Observations with missing information:	6
Percent of observations with data:	92%

Category	Number of Observations	Percent of Observations
Roadside	3	0.1
Drain	394	16.4
Effluent pond	189	7.8
Pond or lake riparian	101	4.2
Pond or lake water	473	19.6
River/stream/creek riparian	357	14.8
River/stream/creek water	85	3.5
Paddock	674	28.0
Farmyard/rural/semi-urban	36	1.5
Wood/shrub field	32	1.3
Other	26	1.1
Hedgerow	8	0.3
Flax hedge	9	0.4
Treed hedge	15	0.6

Definition: The type of habitat class the brood was in when first approached (not the habitat the brood was pushed into). For instance, if the brood was in a paddock but pushed into a drain, the habitat was recorded as paddock.

Notes: Observations with missing information and categories 'hedgerow' and 'other' will be re-assigned to their appropriate class following investigation of brood comments, photographs and digital imagery (where appropriate). Additional type of hedgerows may include: sparse tree/shrub, pampas, gorse or hawthorn.

Categorical variables are difficult to assess because they require a large amount of statistical power and our sample size is only 197 broods. We will

reduce the number of categories by pooling similar habitats together to create 6 habitat types:

1) drains,
2) ponds and lakes and their riparian areas (excluding effluent ponds),
3) effluent ponds;
4) paddocks;
5) rivers, streams, creeks and their riparian areas,
6) other upland habitats (hedgerows, farmyards, roadsides)

Vegetation type

Variable type:	Categorical
Number of categories:	13
Observations with available information:	2029
Observations with missing information:	379
Percent of observations with data:	78%

Category	Number of Observations	Percent of Observations
Grass	1224	50.8
Toe-toe/pampas	28	1.2
Forbs	86	3.6
Sedge/rush	78	3.2
Flax	55	2.3
Raupo	11	0.5
Blackberry	39	1.6
Gorse	139	5.8
Woody ferns	16	0.7
Other shrub	134	5.6
Tree	193	8.0
Artificial (milking shed)	2	0.1
Other	24	1.0

Definition: The dominant type of vegetation within a $5m^2$ area of the brood. For instance, if the brood was in paddock, then veg type was likely grass. If the brood was under a gorse bush in a drain, then veg type should be gorse.

Notes: Other shrub = willow, broom, brush pile, hawthorn.
Tree = Poplar, Macrocarpa, Willows, Manuka, Kahikatea, Pine, etc.
Other = Azolla, water, leaf litter, bare ground, unidentified emergent vegetation.

Usability: Categorical variables are difficult to assess because they require a large amount of statistical power. If future researchers wish to analyse vegetation type as categorical variables, then a category for willows should be created because it occurred commonly in 'other shrub' and 'tree' categories. Brood photos should be examined to properly identify any unidentified vegetation. Over half of the observations reported broods in grass, which may reflect the

use of paddocks. Thus, vegetation type should be considered in conjunction with habitat type (i.e., willows around ponds vs. grass in a paddock).

Percent of overhead cover

Variable type:	Continuous
Observations with available information:	1748
Observations with missing information:	862
Percent of all observations with data:	67%
Percent of observations near water with data:	76%

Definition: Percent of mainly continuous layer of foliage above the brood (within 5 m^2).

Summary: Mean overhead cover was 28.3% (SD = 34.6%). This data is extremely skewed; 44% of observations reported 0% overhead cover which may complicate the analysis. Of the observations that report 0% overhead cover, 45% were recorded in paddocks.

Vegetation height

Variable type:	Continuous
Observations with available information:	796
Observations with missing information:	814
Percent of observations with data:	30%

Definition: Maximum height (excluding excessive outliers) of vegetation within 5 m^2 of the brood.

Summary: Mean vegetation height was 139.5 cm (SD = 296.5 cm; range = 0-4000 cm). Outliers are evident in this data and the larger values certainly represent trees while height of 0 likely represents bare ground. Approximately 56% of the data indicated a vegetation height of <50 cm.

Usability: We have no measure of vegetation height outside of the brood location, therefore we are unable to relate this measure to habitat selection.

Width of the riparian margin

Variable type:	Continuous
Observations with available information:	1584
Observations with missing information:	1026
Percent of all observations with data:	61%
Percent of observations near water with data:	77%

Definition: Defined as the width of the riparian margin (from the edge of the water to the edge of the bank). If the brood was in a large body of water (i.e., pond/lake) only one measurement was reported. If the brood was in a linear waterbody (drain), a measurement was reported for each side.

Notes: During 2014, we recorded the riparian margin of only one side of the drain/river/creek, but in 2015 we recorded width of both sides. If the brood was in a pond or lake, then the riparian margin of the nearest bank was recorded.

Summary: 88% of records are <10 m wide. Of these records, mean riparian width is 1.8 m (SD = 1.8 m). However, 446 observations report a width of 0 m. These records will need to be double-checked to ensure accuracy. To do this, we will review the notes of the brood observations, look at photographs and consult the aerial imagery. Less than 12% of observations report a width for 'riparian side 2'. Of these records, mean riparian width was 1.4 m (SD = 3.8)

Percent of emergent cover

Variable type:	Continuous
Observations with available information:	1253
Observations with missing information:	1359
Percent of all observations with data:	48%
Percent of observations near water with data:	74%

Definition: Only applicable if brood was in a waterbody; emergent vegetation includes aquatic plants that are rooted to the bottom of the waterbody and have grown out of the water, providing vertical cover for broods. Emergent cover may be at the edge of the water or growing throughout the waterbody.

Summary: Averaged emergent cover was 27.0% (SD = 30.4%). 17% of observations report 0% emergent cover. We are unable to determine emergent cover from aerial imagery, so we will refer to brood photographs to interpret missing values or create a Bayesian model that will enable us to interpolate this variable.

Cover type of waterbody

Variable type:	Categorical
Number of categories:	4
Observations with available information:	1487
Observations with missing information:	921
Percent of observations with data:	57%

Cover type	Number of Observations	Percent of Observations
1	119	8.0
2	399	26.8
3	781	52.5
4	188	12.6

Definition: Relevant only if brood was in water. Cover type specifically refers to the amount and arrangement of emergent vegetation around the waterbody.

1: 95% of water surface covered with emergent vegetation

2: 5-95% of water surface is covered with emergent vegetation with interspersed patches of vegetation and open water

3: 5-95% of water surface is covered with emergent vegetation with one central expanse of open water

4: water body is predominately unvegetated with <5% emergent cover around the peripheral edge of the water.
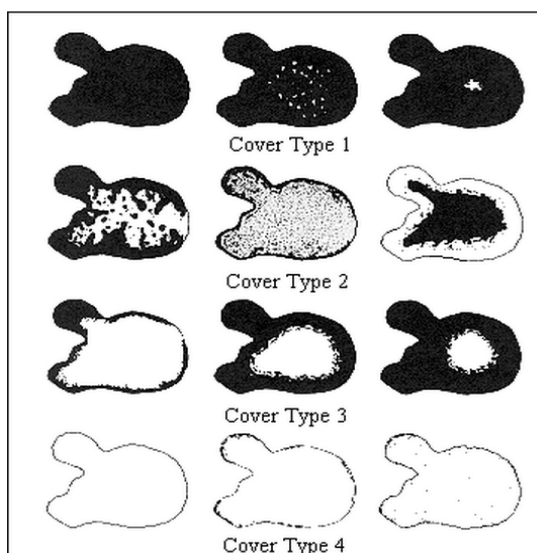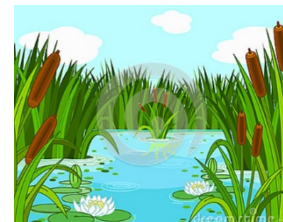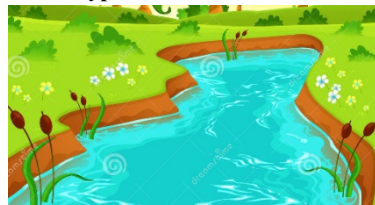
Notes: We did not record cover type for ~650 observations that occurred in upland areas, including paddocks. However, 263 observations that occurred in drains, ponds or streams also lack this information.

Cover type is an important variable that affects brood use and duckling survival in North America (Bloom et al. 2013).

Fenced

Variable type:	Categorical
Number of categories:	3
Observations with available information:	1286
Observations with missing information:	1326
Percent of observations with data:	49%

| Fence type	Number of Observations	Percent of Observations
Fully fenced	1059	82.3
Partially fenced	104	8.1
Not fenced	123	9.6

Definition: Whether the waterbody or area the brood was in was fenced, and if so, if it's completely or partially fenced (i.e., one side of drain is fenced but other is not).

Notes: A portion of observations in 2014 recorded this variable as either yes – fenced or not fenced.

Drain width

Variable type:	Continuous
Observations with available information:	593
Observations with missing information:	2019
Percent of observations with data:	23%
Percent of observations in drains with data:	99%

Definition: The width of the drain (from top of drain's riparian edge to other riparian edge).
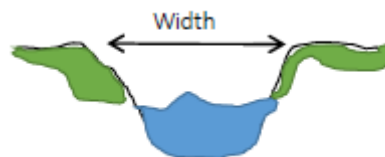
Summary: Mean drain width was 2.8 m (SD = 3.9 m), however the data will need to be checked as outliers or typos are evident (range = 0-80 m). We can use aerial

imagery to verify drain width and to assign widths to drains that were never visited by observations during brood observations.

Drain depth

Variable type:	Continuous
Observations with available information:	577
Observations with missing information:	2035
Percent of observations with data:	22%
Percent of observations in drains with data:	96%

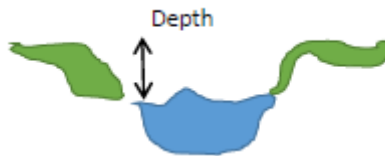**Definition:** The depth of the drain, from top of drain to water level.

Summary: Mean drain depth was 1.4. m (SD = 3.7 m), however the data will need to be checked as outliers or typos are evident (range = 0-80 m). We are unable to determine depth from aerial imagery, so we will create a Bayesian model that will enable us to interpolate this variable.

Drain type

Variable type:	Categorical
Number of categories:	3
Observations with available information:	481
Observations with missing information:	2131
Percent of observations with data:	18%
Percent of observations in drains with data:	78%

Drain type	Number of Observations	Percent of Observations
Natural	154	32.0
Maintained	325	67.6
Unsure	2	0.04

Definition: Whether the drain is maintained or natural.

Maintained: Not much vegetation in drain, sides are steep and possibly lack vegetation (i.e., bare ground). Piles of dirt are evident along drain.

Natural: Vegetation growing on banks and in drain. Drain is densely vegetated and does not look like it has been disturbed in quite some time.

Notes: Unmanaged drains have been linked to higher duck densities (McDougall et al. 2018). Possibly, drain maintenance can be observed from aerial imagery (i.e., presences of berms or dirt piles). If possible, we will attempt to classify this characteristic for all drains throughout the study site.

Drain shape

Variable type:	Categorical
Number of categories:	3
Observations with available information:	440
Observations with missing information:	2172
Percent of observations with data:	17%
Percent of observations in drains with data:	74%

Drain shape	Number of Observations	Percent of Observations
U-shaped	294	66.8
V-shaped	145	33.0
Unsure	1	0.2

Definition: The shape of the drain.

V-shaped: Drain is steep, depth usually greater than 1-2 m; width of water is narrow.

U-shaped: Drain is shallow, width of water in the drain is wider.

Summary: McDougall et al. (2018) found no relationship between drain shape and duckling presence. Drain shape cannot be determine from aerial imagery and because it is a categorical variable we cannot extrapolate missing values using a Bayesian model. We will attempt to classify drain shape of all drains used by broods, and if feasible, we will relate it to duckling survival. However, because we have no measure of the availability of each drain shape throughout the study area, we are unable to assess selection.

Appendix 2 – Summary statistics of the nearest waterbody

Table 10 – Mean ± SD of characteristics of the nearest waterbody for each waterbody type. This information is provided graphically in Figures 10–14.

Waterbody type	Drain	Pond	Lake	River	Stream	Effluent
Area (m^2)	1831.7 ± 1789.7	4461.6 ± 8330.4	317256 ± 408421.1	283134 ± 294312.6	6188.7 ± 9417.4	1010.0 ± 889.4
Vegetation height (cm)	75.1 ± 74.1	240.2 ± 245.8	278.8 ± 84.5	387.5 ± 265.8	126.5 ± 175.0	70.0 ± 80.6
Overhead cover (%)	24 + 25	39 ± 31	54 ± 34	45 ± 37	36 ± 27	13 + 23
Emergent cover (%)	44 + 28	31 + 28	45 + 25	5 + 10	29 + 22	10 + 16
Riparian width (m)	1.3 + 1.1	5.0 + 5.2	50.0 + 42.4	16.1 + 22.6	3.0 + 1.8	3.2 + 1.9
Width (m)	1.8 + 1.0	—	—	30 + 24.6	3.6 + 2.7	—
Depth (m)	1.1 0.9	—	—	—	1.6 + 1.5	—

Appendix 3 – Parameter estimates of duckling survival models

Table 11 - Posterior mean and 95% confidence intervals for logit-scale model parameters used to evaluate brood survival and brood and duckling detection while simultaneously evaluating duckling survival of mallards in Southland and Waikato, 2014–2015.

Model	Parameter	Estimate	LCI	UCI
Model 1: General habitat	**Brood survival**			
	Intercept	3.406	3.075	3.756
	Brood age	0.032	0.017	0.047
	Duckling detection			
	Intercept	1.710	-0.073	5.037
	Brood age	1.650	0.913	1.988
	Brood detection			
	Intercept	7.009	6.131	11.066
	Site (Southland)	0.003	-1.903	1.903
	Year (2015)	-0.008	-1.901	1.899
Model 2: Habitat selection	**Brood survival**			
	Intercept	3.408	3.074	3.765
	Brood age	0.032	0.017	0.048
	Duckling detection			
	Intercept	2.166	0.181	5.700
	Brood age	1.625	0.815	1.989
	Brood detection			
	Intercept	7.985	6.101	11.058
	Site (Southland)	-0.011	-1.904	1.900
	Year (2015)	0.001	-1.892	1.895
Model 3: No selection	**Brood survival**			
	Intercept	3.396	3.058	3.750
	Brood age	0.033	0.018	0.050
	Duckling detection			
	Intercept	2.407	-0.103	6.569
	Brood age	1.561	0.801	1.986
	Brood detection			
	Intercept	7.580	5.855	10.590
	Site (Southland)	0.009	-1.904	1.903
	Year (2015)	-0.009	-1.904	1.903

Table 12 – continued

Model	Parameter	Estimate	LCI	UCI
Model 4: Waterbody features	**Brood survival**			
	Intercept	3.414	3.078	3.769
	Brood age	0.031	-0.020	0.081
	Duckling detection			
	Intercept	1.537	-0.142	4.725
	Brood age	1.652	0.924	1.988
	Brood detection			
	Intercept	7.932	6.065	11.079
	Site (Southland)	0.007	-1.901	1.901
	Year (2015)	0.008	-1.906	1.907
Model 5: Local-scale habitat characteristics	**Brood survival**			
	Intercept	3.439	3.104	3.790
	Brood age	0.031	0.016	0.047
	Duckling detection			
	Intercept	3.586	0.511	11.129
	Brood age	1.460	-0.111	1.987
	Brood detection			
	Intercept	7.875	6.001	10.951
	Site (Southland)	0.009	-1.894	1.905
	Year (2015)	-0.013	-1.904	1.900
Model 6: Local-scale vegetation type	**Brood survival**			
	Intercept	4.101	3.889	4.326
	Duckling detection			
	Intercept	9.075	7.208	12.128
	Brood detection			
	Intercept	7.948	6.072	11.054