



Research Article

Duckling Survival of Mallards in Southland, New Zealand

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ABSTRACT The southern portion of New Zealand's South Island is a productive area for mallards (*Anas platyrhynchos*) despite a notable lack of permanent or semi-permanent wetlands. Most broods are reared in pastures that may or may not be flooded with ephemeral water. In recent years, there has been an increased conversion from continuous to sporadic grazing that has resulted in a functional change in the emergent and upland vegetation available for broods. In 2014, we investigated mallard duckling survival on different pastures relative to a suite of characteristics pertaining to the adult female, clutch, brood, weather, and habitat. We monitored 438 ducklings from 50 radio-marked females to 30 days post-hatch. Duckling survival was unaffected by pasture type but increased with duckling age, the presence of ephemeral water, and with greater distance from the nearest anthropogenic structure. Survival was lower for broods of second year (SY) females than for broods of after-second year (ASY) females, in areas with more dense cover, and when ducklings moved, on average, greater daily distances. Cumulative 30-day duckling survival ranged from 0.11 for ducklings of SY females without ephemeral water present to 0.46 for ducklings of ASY females with ephemeral water present. Therefore, increasing available seasonal water sources may increase duckling survival. Further, narrow, linear patches of dense cover present in our study could support a greater abundance of predators or increase their foraging efficiency. As such, managers could consider increasing patch sizes of dense cover to reduce predator efficiency, and employing predator removal in these areas to improve duckling survival. © 2017 The Wildlife Society.

KEY WORDS *Anas platyrhynchos*, duckling survival, ephemeral water, grazing, habitat, mallard, New Zealand.

Mallards (*Anas platyrhynchos*) comprise the majority of a New Zealand (NZ) gamebird hunter's bag (R.M. Barker, University of Otago, NZ, unpublished report), representing 73% of harvest across the country (Nugent 1992). In addition to their importance to sportsmen, mallard conservation creates and maintains habitat that benefits numerous fish and wildlife species. The New Zealand grey duck (*Anas superciliosa*) and the introduced mallard typically rely on wetlands, lakes, and rivers for feeding, molting, and brood-rearing, and areas of dense natural grass for nesting (Batt et al. 1992, Baldassarre and Bolen 2006). Female mallards are very similar in appearance to the grey duck, and extensive hybridization has led to the combined management of the species. Therefore, herein we refer to mallards, but there is an unknown proportion of the mallard population that includes grey ducks, and grey duck-mallard hybrids (Rhymer et al. 1994, Williams and Basse 2006). Dramatic wetland drainage and landscape change for agricultural development in NZ (MacLeod and Moller 2006) are postulated to have led to the

perceived decline in their combined populations in certain regions (P.J. Teal, NZ Fish and Game, unpublished report).

Nest success (i.e., the probability ≥ 1 egg in a clutch hatches), duckling survival, and adult female survival are key factors affecting waterfowl populations (Hoekman et al. 2002, Amundson et al. 2013, Howerter et al. 2014). Because of the mobile nature of females with ducklings, much less is known about brood ecology than nesting ecology (Sargeant and Raveling 1992, Sedinger 1992, Walker et al. 2013). Despite the challenges of studying brood ecology, previous research has reported duckling survival can be influenced by temperature (Howerter et al. 2014), precipitation (Krapu et al. 2000, Bloom et al. 2012), habitat composition (Krapu and Reinecke 1992; Krapu et al. 2000, 2004), food availability (Sedinger 1992, Baldassarre and Bolen 2006), season date (Dawson and Clark 2000, Krapu et al. 2000, Amundson and Arnold 2011), and female characteristics (age: Devries et al. 2003, 2008; Kaminski et al. 2013; body condition: Krapu 1981, Rotella et al. 2003; brood size: Afton and Paulus 1992, Johnson et al. 1992, Dzus and Clark 1997a). These effects are particularly pronounced early in life (Krapu et al. 2006, Amundson and Arnold 2011, Bloom et al. 2012).

Only 8% of wetlands in NZ remain from pre-European times (Jones et al. 1995). Consequently, the rural landscape

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of NZ has reduced vast wetland areas to a few mostly man-made, small ponds. Thus, mallard broods tend to be reared in pastures. During heavy periods of rain, ephemeral wetlands (i.e., shallow, temporary bodies of water in soil depressions) form where topography and tile drainage allow. Ducklings require sufficient protein for adequate growth and development, and ephemeral water bodies contain numerous aquatic invertebrates, a primary duckling food source (Street 1978, Sedinger 1992). Further, ephemeral water saturates the soil, forcing earthworms to the surface where they are foraged upon by ducklings (Swanson et al. 1985, Sedinger 1992, Cox et al. 1998). Additionally, the presence of ephemeral wetlands might reduce overland movement by ducklings, thus reducing energy expenditure and exposure to predators, improving their survival (Ball et al. 1975).

Habitat composition may also affect duckling movement and predation rates. Livestock pasture is the dominant land use in NZ and notable seasonal habitat differences exist among pastoral management systems. Sheep and deer tend to be set-stocked with animals distributed at low density across all pastures for lambing and fawning, which coincides with the mallard nesting and hatching period. This practice results in pastures with continually grazed short grass and frequent animal disturbance but minimal anthropogenic disturbance. In contrast, the majority of dairy pastures in NZ are left ungrazed until the completion of calving, which coincides with the nesting and hatching period. Pastures are then rotationally grazed with brief periods when cattle are distributed at high density, causing high anthropogenic and animal disturbance. In some cases, dairy pastures are left to reach ceiling yields (i.e., the period just prior to seeding when pasture quality starts to decline) when they will be cut for silage, usually later in spring. As a result, grass height is much taller and denser in dairy pastures during the mallard brood-rearing season and differs from deer and sheep systems in the amount of human and animal disturbance, vegetation density, and structure, which could result in differential habitat use, movement rates, and predation risk in these areas. Habitat composition influences the occurrence, density, and foraging behavior of potential predators (Bloom et al. 2012). The native swamp harrier (*Circus approximans*) is a gamebird predator in NZ, and introduced species including stoat or short-tailed weasel (*Mustela erminea*), least weasel (*M. nivalis*), ferret (*M. putorius furo*), and feral cat (*Felis catus*) substantially affect native and introduced wetland-dependent birds in NZ (O'Donnell et al. 2015).

Most knowledge of duckling ecology comes from studies of radio-marked brooding females in temperate North America, which might not be relevant to mallard ducklings in NZ. Previous research suggests duckling survival and factors affecting survival vary substantially in location and time, likely as a result of fluctuating environmental conditions and habitat availability (Baldassarre and Bolen 2006). To date, no published studies report estimates of mallard duckling survival or factors affecting survival in NZ, or how 2 very different pastoral management systems may affect survival of ducklings that are predominantly reared in pastures. Thus, in

2014, we marked breeding female mallards with very high frequency radio-transmitters and followed broods in Southland, NZ to estimate mallard duckling survival to 30 days of age, and evaluate the effects of habitat, weather, and brooding female characteristics on duckling survival. We hypothesized that young ducklings would have relatively low survival rates if they experienced poor (i.e., cold, wet) weather conditions early in life, were reared in areas with no ephemeral water bodies, or were reared on dairy pastures containing tall, dense cover.

STUDY AREA

The study was conducted on a 30-km² site centered on the Lochiel community (46°12'18.68"S, 168°19'46.19"E) just south of Winton, Southland, on the South Island of NZ (Fig. 1). The boundaries of the study site were defined by the outermost locations of marked females recorded throughout the study period. New Zealand mallards breed in the Austral spring and summer (Sep–Feb), initiating nests as early as August with peak brood rearing in October and November. The total mean annual rainfall is 959 mm, with most precipitation occurring in the summer during January (101 mm) and the least in winter during July (63 mm; Macara 2013). Temperatures average 14°C and 5°C in summer and



Figure 1. New Zealand with a white star denoting the study site within the country.

winter, respectively (Macara 2013). The region is typical of those across the country, encompassing a range of landscapes characterized by coastlines, mountain ranges, foothills, and the Southland plains (Critchfield 1954, Cochrane 1960). Within this region, the study site was limited to the more homogenous plains country (elevation = 32–40 m asl) where intensive agriculture dominates the landscape, specifically dairy cattle, sheep, and deer that are farmed on predominantly rye grass (*Lolium perenne*) pastures, bifurcated by rivers and associated river flats. The study area was exclusively private land with numerous small man-made ponds created to hold livestock waste (effluent ponds) or serve as waterfowl habitat. It is thought that the majority of Southland's mallards are produced across these plains (M. A. Rodway, NZ Fish and Game, personal communication). The remaining land cover is limited to road verges or ditches of rank grass and shelterbelts of typically macrocarpa (*Cupressus macrocarpa*), gum trees (*Eucalyptus* sp.), or flax (*Phormium tenax*).

METHODS

Capture and Marking

Beginning 5 July 2014, we captured female mallards at 3 locations using walk-in baited funnel traps (Cleary 1994). We selected sites used for female capture within this region from aerial images on the basis of representative mallard habitat for the area, landowner permission, and where no hunting was undertaken in the weeks leading up to capture. Thus, we assumed females captured were representative of the local population. Upon capture, we attached an NZ Department of Conservation metal leg band with a unique number to the left leg of each female. We determined age as second year (SY) or after second year (ASY) primarily by bursa depth (Hanson 1949), and then by inspecting the greater secondary coverts (Krapu et al. 1979) and 4 distal primary coverts (Carney and Geis 1960, Hopper and Funk 1970, Pearse et al. 2014). We weighed birds with a spring scale (± 10 g; Pesola, Schindellegi, Switzerland).

We anesthetized females using isoflurane ($\bar{x} = 6.3$ mL) in a surgery unit and implanted each bird with a 22-g radio-transmitter (Model IMP/150, Telonics, Mesa, AZ, USA; modified from Olsen et al. [1992]) in the abdominal cavity lateral to the liver. This type of intra-abdominal transmitter has negligible effects on reproductive effort in other waterfowl in comparison to other options such as external antenna implants (Rotella et al. 1993, Paquette et al. 1997). Pre-operative handling and surgery time averaged 16 minutes and 22 minutes, respectively. After surgery and upon waking, we placed females in a crate for 45 minutes to recover and then released females near their capture sites. In accordance with the Animal Welfare Act 1999, all procedures used in this study were approved by the University of Auckland Animal Ethics Committee (Protocol no. 001331) and cleared by the University of Otago under this permit.

Brood Observations

We located radio-marked females by triangulation every 2–5 days using vehicle-mounted, null-peak antenna systems

(Gilsdorf et al. 2008). Once we triangulated a female to the same location 3 consecutive times, we approached by homing to her radio signal to determine nesting status. If we found the nest, we candled the eggs to determine incubation status (Weller 1956). We recorded egg measurements (length and width) with Vernier calipers to the nearest 0.1 mm, and revisited the nest every 7–10 days until we determined nest fate (failed or hatched). If the nest failed, we monitored the female weekly until any re-nesting attempt was initiated, at which time monitoring resumed as above. If the nest hatched successfully, we located the brood via homing telemetry every day for the first 10 days post-hatch, with visual contact made every 3 days if possible, and thereafter every 5 days until the female could no longer be found, or until ducklings reached approximately 30 days of age. Once a female was seen without ducklings over 2 consecutive resightings, we assumed total brood failure had occurred and monitored her weekly to check for re-nesting.

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

We used ArcGIS (version 10.2; ESRI, Redlands, CA, USA) to create a digitized land-cover layer from color aerial photographs (cell size of 0.4 m, resolution 1:1500) taken 5 February 2014 by New Zealand Aerial Mapping (NZAM; Hastings, NZ). This level of detail allowed land cover types to be easily delineated into 5 categories: permanent water (e.g., ponds, streams, and ditches), anthropogenic features (e.g., houses and roads), dairy pastures, sheep and deer pastures, and dense cover (e.g., rank grass, road edges, woodlots, hedgerows). We confirmed digitized land cover maps via ground-truthing to verify layer accuracy. We used the Near tool in ArcGIS to generate distances to closest habitat features from the centroid of each brood location. For brood movement, we used the Split at Vertices tool in ArcGIS to estimate distances traveled between locations assuming a straight line trajectory. We averaged distances across observations from nest site to the last known-alive location, or until the brood reached 30 days of age.

Brood Data

We defined brood size as the number of ducklings that successfully left the nest bowl. We determined egg volume using the average length (l) and breadth (b) of all eggs in the nest, with corresponding egg volume calculated with the formula $\text{Volume} = K_v lb^2$, with $K_v = 0.515$, a constant specific for mallards (Hoyt 1979).

We downloaded minimum air temperature and precipitation from the National Climate Database (cliflo.niwa.co.nz) using data collected from the weather station 600 m north of the study site (Winton2, Agent no. 5768). We weighted both precipitation and minimum temperatures over the first 10 days post-hatch using a linear decay where day 1 was most important to duckling survival to account for the adverse weather during the early post-hatch period (Amundson and Arnold 2011).

We digitized brood locations in ArcGIS from field maps created over the season. A successful brood was confirmed by the observation of ≥ 1 ducklings surviving to 30 days post-hatch. We had initially hoped to observe ducklings until fledge (day 52–60 in North America; Afton and Paulus 1992, Rhymer 1992, Baldassarre and Bolen 2006), and although many of the females were actively tracked until ducklings reached ≥ 45 days old, we chose 30 days as a cut-off measure for 3 reasons. First, counts became more difficult past this point because females took brood breaks and because frequent creching behavior (brood amalgamations) made unique brood counts difficult (Eadie et al. 1988, Afton and Paulus 1992, Johnson et al. 1992). Second, previous waterfowl studies suggested little change in survival between 30 and 45 days (Orthmeyer and Ball 1990, Rotella and Ratti 1992, Amundson and Arnold 2011). Third, this allows for a comparable estimate to other duckling survival studies that typically assessed survival to 30 days post-hatch (Baldassarre and Bolen 2006, Amundson and Arnold 2011, Bloom et al. 2013).

We defined each duckling count as being full (i.e., ducklings were fully visible and believed to be accurately counted by the observer), suspected partial (i.e., incomplete duckling count only), mixed (i.e., ducklings of various ages exhibiting creching behavior), or unknown based on the degree of certainty of the observer. We assumed full counts to be most reliable, with partial counts providing additional data. If counts fluctuated, we erred on the conservative side, relying on full counts and later observations when brood detectability increased.

We measured habitat variables to the last known-alive location for ducklings within a brood that went missing during the same interval because we rarely knew exactly when (and where) death occurred. For ducklings that left the nest bowl but were not observed for any post-hatch count, we measured habitat variables from the nest site. We determined the number of ducklings that left the nest bowl by visiting the nest <24 hours after hatch, and counting unhatched eggs (Klett et al. 1986). If the female died before the brood reached 30 days of age, we censored the brood from the time of female mortality (i.e., when ducklings were last observed with the F).

We created brood routes in ArcGIS using the Point to Line feature, assuming straight-line movement from the nest site to first female location and to subsequent known, consecutive locations until the female was last observed with ducklings, or ducklings reached 30 days of age. We created a 50-m-radius buffer to assess categorized habitat on either side of the segmented straight-line movements using the

Buffer and Clip tools in ArcGIS. A 50-m-radius buffer (100-m diameter) was approximately equal to the average distance moved per day for broods in our study. We made brood movement an artificial straight-line trajectory because the actual route taken was unknown but presumably within the buffer. We calculated the daily distance traveled between consecutive locations and used the mean daily distance traveled for movements that occurred over >1 day.

Statistical Analysis

We considered a set of variables on individual duckling survival including environmental, temporal, and female characteristics that have been supported previously in other waterfowl survival studies or apply directly to habitat management in NZ. Specifically, the set of variables included a log-linear trend for duckling age, effects of female age (SY or ASY), length of grass in pasture where the brood spent the majority of its first 10 days of life (long or short), the presence or absence of ephemeral water within 100 m of the brood route, within-season hatch date (where day 1 = 11 Sep 2014, the date of the first successful nest), brood size, egg volume, 10-day average weighted precipitation, average distance to anthropogenic sources, average distance to permanent water body, percentage of dense cover within brood routes, and average distance moved between consecutive brood locations. We initially considered the effect of temperature measured across the first 10 days of life on duckling survival, but this was strongly correlated with season date and preliminary analyses suggested season date had greater predictive power than temperature; thus, we did not include it in the final variable set. Remaining covariates were at most weakly correlated (r range = -0.23 to 0.37). We centered and standardized ($\bar{x} = 0$ and $SD = 1$) all continuous variables to facilitate model convergence and comparison of effect sizes.

We were unable to identify the exact failure date for ducklings because broods were not monitored daily. Rather, we knew they had died during the interval between last being seen alive and observing the brood without ≥ 1 ducklings. Thus, these data are referred to as ragged telemetry data for which analysis of known fates is inappropriate (Dinsmore et al. 2002, Rotella et al. 2004). Instead, we completed analyses using the Nest Survival module of Program MARK, which estimates model parameters using a likelihood function appropriate for these data (Rotella et al. 2004, White 2015). Although individual ducklings were the sampling unit, we anticipated correlation in survival among broodmates because ducklings within a brood are exposed to the same adult female characteristics and temporal and environmental factors, which leads to overdispersion in the data. To test this assumption, we conducted a chi-square test of duckling independence by selecting random subsets of 25 broods in our dataset and running each in an age-only model to estimate daily survival rate. We then used survival rates on the withheld data to obtain the expected number of live and dead ducklings per brood based on the number of days each duckling survived (Winterstein 1992: test 3). We ran replicates and removed those with cells that had expected values <1 until we had 250 subsets (Freeman 1987, Winterstein 1992). We found fates of ducklings within a brood

were not independent ($\chi^2_{24} = 318.2$, $P < 0.001$, range = 163.6–3,401). Not accounting for overdispersion in our data may bias variance estimates low and result in selecting overparameterized models (Burnham and Anderson 2002). We did not want to lose valuable information on duckling-specific exposure days and conduct the analysis per brood as recommended by Flint et al. (2006). Thus, we estimated overdispersion (variance inflation factor, $\hat{c} = 4.53$) by running 5,000 bootstrap simulations in Program MARK on the most parameterized model in the candidate set (Bishop et al. 2008). We used Akaike's Information Criterion adjusted for small sample size (AIC_c) to evaluate relative model fit (Burnham and Anderson 2002). We then adjusted AIC_c to quasi- AIC_c ($QAIC_c$) and inflated variances of parameters by \hat{c} (Symonds and Moussalli 2011). We report standard error for coefficients and predictions and derived 85% confidence intervals around cumulative survival estimates using Markov chain Monte Carlo simulations (Amundson and Arnold 2011).

We carefully selected our covariate set to include only biologically plausible and management-related covariates that were important in other examinations of duckling survival. Nevertheless, we did not have specific hypotheses for which variables or combination of variables would be most supported for mallards in NZ, with 1 exception. Duckling age influences survival, with survival rate typically increasing as ducklings get older (Krapu et al. 2006, Amundson and Arnold 2011). Thus, we included a log-linear trend in duckling age in all models, and examined all possible subsets of the remaining 11 covariates (1,024 models; Doherty et al. 2012).

We then calculated variable importance weights (i.e., the sum of the $QAIC_c$ weight for all models containing a particular covariate) to determine relative support for each covariate (Arnold 2010). We model-averaged cumulative survival estimates but report only the coefficients for the most supported model (i.e., lowest $QAIC_c$ value) that included variables with importance weight ≥ 0.5 (Bishop et al. 2008, Banner and Higgs 2017).

RESULTS

Between 5 July and 22 September 2014, we implanted 62 females with abdominal transmitters and attached prong-and-suture transmitters to 23 nesting females. Three abdominally

implanted females died within 3 days, likely because of wet, cold, and muddy conditions during marking. The remaining 82 females hatched young from 55 nests. We censored 5 successful nests from analyses because of responses to investigator disturbance ($n = 4$) or transmitter failure upon nest exodus ($n = 1$). Therefore, we included 438 ducklings from 50 broods in the analyses. One female was killed by mowing machinery before her brood reached 30 days of age. Mean egg volume was 56.80 cm^3 (range = 45.68–67.88) and mean brood size was 9.06 ducklings (range = 5–15). We monitored broods from 11 September to 23 January 2015, with the last nest hatched 4 January 2015 (median = 26 Sep 2014). In total, 141 ducklings from 27 broods survived to 30 days post-hatch, and 22 broods experienced total failure. Our sample included more ASY ($n = 29$) than SY ($n = 21$) females and approximately half of broods were reared in predominantly dairy pastures ($n = 26$) and half of all broods had ephemeral water present ($n = 25$). The land cover over the entire study area was categorized as 8.9% dense cover (i.e., hedgerows, road verges, ditch edges, wetlands), 45.7% short sheep or deer farm pasture, and 45.4% long dairy pastures, with varying proportions represented in the used-route buffer for each female.

The most-supported model for duckling survival included the log-linear trend for duckling age, female age, ephemeral water, distance to anthropogenic sources, percentage of dense cover, and distance moved. Several models received equivalent support (i.e., $\Delta QAIC_c < 2$; Garrick 2016); however, the most-supported model included all variables with variable importance weights > 0.5 (Table 1) and the addition of covariates did not further reduce $QAIC_c$ values (Burnham and Anderson 2002). Duckling survival increased with duckling age ($\beta = 0.05 \pm 0.02$ [SE]), was greater when ephemeral water was present ($\beta = 0.578 \pm 0.299$), and increased with greater average distance between brood locations and the nearest anthropogenic structure ($\beta = 0.278 \pm 0.181$; Fig. 2). Duckling survival was lower for SY than ASY females ($\beta = -0.516 \pm 0.267$), in areas with increased dense cover ($\beta = -0.375 \pm 0.154$; Fig. 3), and when ducklings moved, on average, greater distances ($\beta = -0.33 \pm 0.160$; Fig. 4). Model-averaged cumulative duckling survival to 30 days of age ranged from 0.157 for SY females without ephemeral water present in short pasture to 0.423 for

Table 1. Variable importance weight and its relationship to mallard duckling survival in Southland, New Zealand, 2014. We interpreted associations for parameters in the most supported model based on quasi-Akaike's Information Criterion adjusted for small sample size ($QAIC_c$) values and with importance > 0.5 .

Parameter	Importance	Association
% dense cover within brood routes	0.81	–
Female age	0.68	– (second-year)
Ephemeral water within 100-m of brood route	0.67	+ (when present)
Average distance moved between consecutive brood locations	0.65	–
Average distance to anthropogenic sources	0.52	+
Egg volume	0.39	
Brood size	0.36	
Within-season hatch date	0.33	
Pasture type where broods spent the majority of their first 10 days of life	0.32	
Average distance to permanent water	0.31	
10-day average weighted precipitation	0.28	

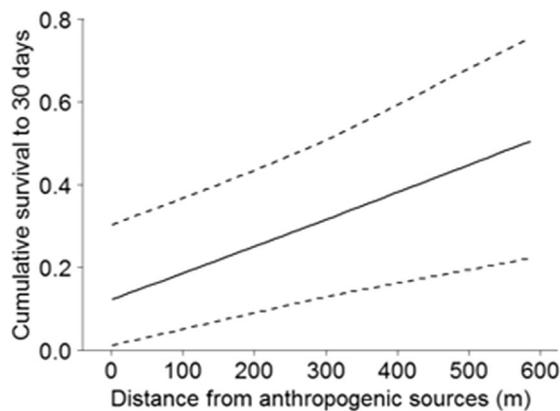


Figure 2. Model-based estimates of cumulative duckling survival to 30 days of age (solid line) with 85% confidence interval (dashed lines) in relation to the average distance from anthropogenic sources (e.g., houses, roads) of the brood route for mallard broods in Southland, New Zealand, 2014. Mean distance from anthropogenic sources was 234.5 m. Estimates are for after-second-year females without ephemeral water present with continuous covariates held at mean values (area of dense cover per brood route = 13.2%, distance moved = 118.4 m, initial brood size = 9.06 ducklings).

ASY females with ephemeral water present in long pasture (Table 2). For the most-supported model, mean cumulative duckling survival to 30 days of age for broods with ephemeral water present was 0.277 ± 0.043 (85% CI = 0.217–0.342) for SY females and 0.462 ± 0.037 (85% CI = 0.409–0.514) for ASY females; without ephemeral water present, duckling survival was 0.106 ± 0.027 (85% CI = 0.069–0.15) and 0.256 ± 0.038 (85% CI = 0.203–0.312) for SY and ASY females, respectively.

DISCUSSION

Contrary to game managers' concerns, overall pasture management did not appear to be a significant factor affecting duckling survival for mallard broods in Southland, NZ.

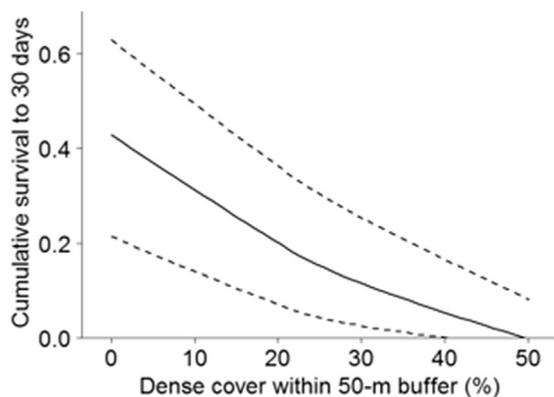


Figure 3. Model-based estimates of cumulative duckling survival to 30 days of age (solid line) with 85% confidence interval (dashed lines) in relation to the percent of dense cover within the 50-m radius buffer for mallard broods in Southland, New Zealand, 2014. Mean percent of dense cover = 13.2%. Estimates are for after-second-year females without ephemeral water present with continuous covariates held at mean values (distance to anthropogenic sources = 234.5 m, distance moved = 118.4 m, initial brood size = 9.06 ducklings).

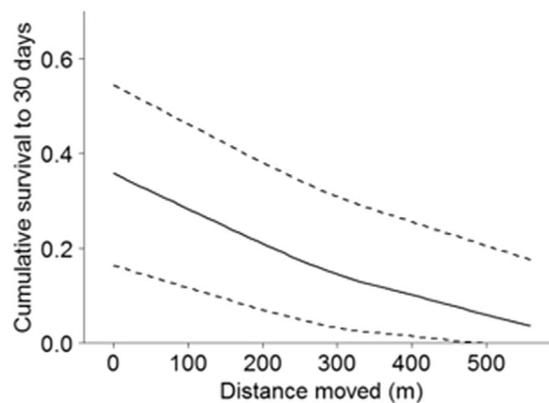


Figure 4. Model-based estimates of cumulative duckling survival to 30 days of age (solid line) with 85% confidence interval (dashed lines) in relation to average daily distance moved for mallard broods in Southland, New Zealand, 2014. Mean daily distance moved = 118.4 m. Estimates are for after-second-year females without ephemeral water present with continuous covariates held at mean values (dense cover per brood route = 13.2%, distance to anthropogenic sources = 234.5 m, initial brood size = 9.06 ducklings).

Nevertheless, several factors influenced duckling survival, including the percentage of dense cover within the route buffers, female age, presence of ephemeral water within areas used by broods, distance moved, and distance from an anthropogenic source.

Pasture type might not have been associated with duckling survival for several reasons. First, the categories were coarse (dairy farms with long grass or other livestock pastures with short grass) and individual livestock management regimes or even landowner differences could have obscured broad patterns in pasture type that might relate to duckling survival. Second, pasture type might affect duckling survival in opposing ways that, when combined, result in no net effect. For example, longer pastures in dairy management systems may reduce detection of ducklings by both aerial and mammalian predators, but this advantage could be offset by ducklings expending more energy when traversing long, thick grass, especially when young. Conversely, sheep and deer pastures contain short grass facilitating detection of broods by predators, but high visibility may also facilitate predator detection and escape.

Consistent with previous North American studies (Devries et al. 2003, 2008; Rotella et al. 2003; Mack and Clark 2006; Kaminski et al. 2013), female age had a positive impact on duckling survival, with ASY females having more than double the duckling survival of SY females. This is most likely due to the lack of brood-rearing experience of younger females (Rotella et al. 2003), but the actual mechanism is unknown.

Hatch date and precipitation did not appear in the most supported model. New Zealand has relatively mild weather conditions in comparison to North America and thus, likely has more stable food resources for broods and less inclement weather requiring additional energy expenditure by ducklings. Gendron and Clark (2002) suggested that high quality wetland conditions throughout the breeding season were a better predictor of duckling survival than hatch date in

Table 2. Model-averaged estimates of cumulative duckling survival to 30 days post-hatch for mallard ducklings in 8 attribute groups related to female age (SY = second-year, ASY = after-second-year), pasture type (long grass, short grass), and whether ephemeral water was present during brood-rearing in Southland, New Zealand, 2014.

F age	Pasture	Ephemeral	Estimate	SE	85% LCI	85% UCI
SY	Short	Yes	0.277	0.109	0.129	0.447
SY	Short	No	0.157	0.089	0.050	0.302
SY	Long	Yes	0.296	0.117	0.134	0.475
SY	Long	No	0.173	0.097	0.053	0.328
ASY	Short	Yes	0.404	0.099	0.267	0.550
ASY	Short	No	0.267	0.101	0.132	0.423
ASY	Long	Yes	0.423	0.095	0.283	0.563
ASY	Long	No	0.285	0.098	0.151	0.436

Canadian prairies. The presence of ephemeral water bodies on brood routes during periods of high rainfall in this study combined with the mild climate, may explain equivalent survival of early and late nesting birds.

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

Our 30-day cumulative duckling survival estimate is the first for mallards in NZ. Mean cumulative duckling survival was 31.3% (85% CI = 29.5–33.1), which is lower than in the Canadian Prairie Pothole region where 30-day cumulative duckling survival averaged 52.3% (SE = 0.009) for decoy-trapped females with abdominal transmitters and 53.9% (SE = 0.014) for females that were nest-trapped with back-mounted transmitters (Bloom 2010). Our results are similar to estimates from California (24.8%, 95% CI = 17.8–33.5; Chouinard and Arnold 2007), control sites in south-central Saskatchewan, Canada (35.7%, 90% CI = 27.5–45.6; Pearse and Ratti 2004), and North Dakota, where survival ranged from 15.7% (85% CI = 8.4–25.2) in 2006 to 26.4% (85% CI = 19.3–35.5) in 2007 (Amundson and Arnold 2011). Several North American studies suggest duckling survival similar to or greater than levels we observed influenced mallard population growth (Coluccy et al. 2008, Amundson et al. 2013, Howerter et al. 2014). Thus, although the influence of duckling survival on population dynamics of mallards in NZ remains unknown, management actions to increase duckling survival will increase mallard production and may influence populations in the region.

Duckling survival was correlated among broodmates; almost half of the broods in our study experienced total loss. These results suggest predation by those species adept at killing an entire brood, or disturbance from predation or other events affected all ducklings within a brood (e.g., events unrelated to individual duckling quality). We did not assess cause-specific mortality in our study, however, and this warrants further investigation. Consequently, our data were overdispersed and \hat{c} was slightly higher than other studies of mallard duckling survival in the Prairie Pothole Region ($\hat{c} = 3.6$, Amundson and Arnold 2011; $\hat{c} = 3.98$, Bloom et al. 2012). Adjusting for this overdispersion in the data increased uncertainty in our parameter estimates and model selection. Therefore, our results are likely conservative and future studies may want to consider alternative analysis frameworks that parse error into process and random components (e.g., Bayesian; Schmidt et al. 2010).

Permanent and semi-permanent wetlands are often present in brood-rearing areas. Nevertheless, these water bodies may provide poor quality habitat in terms of survival for mallard broods (Chouinard and Arnold 2007). In North Dakota, studies suggest duckling survival is positively correlated with the percentage of seasonal basins containing water, with use

increasing during the wet period, suggesting the conservation and restoration of seasonal wetlands benefits mallard productivity (Hoekman et al. 2004, Krapu et al. 2006, Bloom et al. 2012). In years when there is an abundance of seasonal ponds, broods in those North Dakota environments can avoid the permanent water bodies that have lower invertebrate food resources (Euliss et al. 1999) and are preferred by predators such as mink (*Neovison vison*; Krapu et al. 2004). In Southland, the presence of ephemeral water within the brood route during the first 10 days post-hatch increased cumulative duckling survival by approximately 13%. This result is not surprising considering the abundant food resources available within temporary, shallow bodies of water across pastures, reducing feeding time and possibly, exposure to terrestrial predators (Swanson et al. 1985, Euliss et al. 1999, Krapu et al. 2006).

Duckling survival increased with distance from anthropogenic sources. Typically, activities associated with houses and farm buildings result in increased levels of disturbance for broods (Korschgen and Dahlgren 1992) and an increase in predator abundance (Thorington and Bowman 2003). The distance traveled overland by ducklings was negatively correlated with duckling survival, a finding consistent with several studies (Ball et al. 1975, Rotella and Ratti 1992, Mauser et al. 1994, Bloom 2010, Bloom et al. 2012), but contradicts other reports that found no effect of overland movement on duckling survival (Talent et al. 1983, Dzus and Clark 1997b). Overland movement may increase duckling vulnerability to predation, starvation, and separation from their broodmates, particularly when movement is through dense cover. Chouinard and Arnold (2007) noted that short brood movements and small home ranges were correlated with areas where wetlands were contiguous. Consequently, the provision of seasonally flooded wetlands adjacent to nesting habitat may increase the survival of broods by increasing proximal food availability and by decreasing the necessary movement overland. Nevertheless, the mean distance traveled was similar for broods with and without ephemeral water present ($\bar{x} = 119.45$ m [SD = 70.9] and 105.74 m [SD = 86.38], respectively), suggesting broods did not move farther in search of ephemeral water if none was present. Areas without ephemeral wetlands present may have had sufficient food resources for broods, or limited food resources outweighed the costs of additional overland movement. Future work examining duckling diets and food availability in this landscape may shed light on our results.

MANAGEMENT IMPLICATIONS

Although pasture management did not influence duckling survival in this study, our results clearly demonstrate the importance of the presence of ephemeral water, which improved duckling survival of brooding females in both age classes. Given this, we suggest managers improve habitat for brood survival through actions such as prevention and removal of sub-surface drainage in pastures, and seasonal wetland creation. Habitat enhancement may be especially beneficial in areas relatively far from anthropogenic structures. Further, if duckling survival is negatively associated with dense

cover through increased predation efficiency in narrow, linear habitats, then predator removal in our study area may have the potential to increase duckling survival, but management actions need to be evaluated to determine their effectiveness.

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