Tools and Technology

Effects of Surgically Implanted Transmitters on Reproduction and Survival in Mallards

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ABSTRACT Abdominally implanted radiotransmitters have been widely used in studies of waterbird ecology; however, the longer handling times and invasiveness of surgical implantation raise important concerns about animal welfare and potential effects on data quality. Although it is difficult to assess effects of handling and marking wild animals by comparing them with unmarked controls, insights can often be obtained by evaluating variation in handling or marking techniques. Here, we used data from 243 female mallards (*Anas platyrhynchos*) and mallard–grey duck hybrids (*A. platyrhynchos × A. superciliosa*) equipped with fully encapsulated abdominally implanted radiotransmitters from 2 study sites in New Zealand during 2014–2015 to assess potential marking effects. We evaluated survival, dispersal, and reproductive effort (e.g., breeding propensity, nest initiation date, clutch size) in response to 3 different attributes of handling duration and procedures: 1) processing time, including presurgery banding, measurements, and blood sampling of unanaesthetized birds; 2) surgery time from initiation to cessation of anesthetic; and 3) total holding time from first capture until release. We found no evidence that female survival, dispersal probability, or reproductive effort were negatively affected by holding, processing, or surgery time and concluded that we collected reliable data without compromising animal welfare. Our results support previous research that techniques using fully encapsulated abdominal-implant radiotransmitters are suitable to enable researchers to obtain reliable estimates of reproductive performance and survival. © 2017 The Wildlife Society.

KEY WORDS abdominal-implant, *Anas platyrhynchos*, breeding propensity, holding time, mallard, nest initiation date, processing time, surgery time, survival, telemetry.

Over the past 50 years, ecologists have used radiotelemetry to study survival, movement, and behavior of waterbirds, including shorebirds, cranes, grebes, loons, ducks, geese, swans, albatrosses, penguins, and alcids (e.g., Greenwood and Sargeant 1973, Klugman and Fuller 1990, Meyers et al. 1998, Green et al. 2004, Mulcahy et al. 2011). In particular, telemetry-based breeding-season survival rates and habitat selection patterns have informed management and conservation practices of game birds (Cowardin et al. 1985, Davis et al. 2014, Howerter et al. 2014, Gibson et al. 2016). Usually, investigators make the fundamental assumption that capture and marking techniques do not bias parameters of interest such as behavior, reproductive effort, survival, or movement (Barron et al. 2010). In a recent meta-analysis, Barron et al. (2010) suggested that implanted and anchored transmitters had the greatest reported device-induced mortality when compared with other attachment methods (e.g., harness, collar, glue, and tail-mounted). Conversely, White et al. (2013a) demonstrated that externally attached devices had consistent detrimental effects on body condition, survival, and reproduction, and suggested that implant transmitters are preferable. Equivocal results create difficulties when deciding which marking techniques are most appropriate for a given study. Thus, researchers should test assumptions of marker effects on parameters of interest to prevent unreliable conclusions being drawn from potentially biased data (Barron et al. 2010).

Initially, radiomarkers designed for waterfowl were externally mounted (e.g., backpacks or back-mounted), but adverse effects such as mass loss, feather wear, and abnormal behavior led researchers to develop abdominally implanted transmitters (Dwyer 1972, Greenwood and Sargeant 1973, Perry 1981, Korschgen et al. 1984). Since then, surgical techniques have been modified and refined to minimize handling stress and mortality, including use of general anesthesia, intubation and heart-rate monitoring, and improved aseptic and sterilization methods (Mulcahy and Esler 1999). Abdominal-implant techniques involve a relatively invasive surgical procedure requiring more facilities, additional personnel, and

specialized equipment. As a result, handling and holding duration is often increased, and risks to study animals may be greater than for other attachment techniques (Olsen et al. 1992, Esler et al. 2000*a*). In combination with additional data collection (e.g., collection of biometric measurements and blood samples), handling and holding times of birds may be overly prolonged and unknowingly affect individual welfare or measured vital rates.

Although earlier studies reported greater survival, return rates, and reproductive effort of waterfowl when equipped with abdominally implanted transmitters as opposed to back-mounted or harness-style devices, more recent investigations into effects of abdominally implanted transmitters have been ambiguous (Rotella et al. 1993, Dzus and Clark 1996, Paquette et al. 1997, Esler et al. 2000*a*). For instance, abdominally implanted transmitters did not affect survival of tundra swans (*Cygnus columbianus*; Ely and Meixell 2016) or short-term survival, behavior, time budgets, or fecundity of Canada geese (*Branta canadensis*; Hupp et al. 2003, 2006). Further, researchers detected no difference in survival among surf and white-winged scoters (*Melanitta perspicillata* and *M. fusca*, respectively) equipped with external (prong-and-suture) or internal transmitter types (Iverson et al. 2006). In contrast, common eiders (*Somateria mollissima*) exhibited lower first-year survival, behavioral changes, reduced foraging, and adverse physiological responses after surgical implantation of satellite transmitters with percutaneous antennas (Latty et al. 2010, 2016; Fast et al. 2011). Despite the wide application of surgically implanted transmitters, studies rarely address potential effects that variations in processing, surgical, and total holding time have on study subjects even though postsurgery censor periods may be required (McMahon et al. 2011, Latty et al. 2016). More importantly, understanding how marker effects influence demographic parameters of interest is especially paramount if conservation and management decisions are derived from research programs (e.g., Hooijmeijer et al. 2014, Uher-Koch et al. 2014, Hupp et al. 2015).

Evaluating population vital rates often requires that individuals can be identified, which creates difficulties when assessing effects of marking wild animals because vital rates of unmarked controls are difficult to establish. Fortunately, variations in capture and handling techniques during a given procedure can be used as metrics to evaluate subsequent survival and reproductive performance. Mallards (*Anas platyrhynchos*) were introduced to New Zealand in the late 1800s and have since become an economically important game bird (Dyer and Williams 2010, McDougall and Amundson 2017). We combined mallard and mallard–grey duck hybrids (*A. platyrhynchos* × *A. superciliosa*; hereafter, mallard) in our study because females of both species are phenotypically similar, largely introgressed (Williams and Basse 2006), and jointly managed and monitored throughout the country. In 2014, we initiated a 2-year telemetry study to investigate habitat selection and breeding ecology of mallards on 2 study sites in New Zealand. Here, we examined effects of variations in capture and handling procedures during

abdominal implantation of radiotransmitters on subsequent survival, dispersal, and reproductive effort of wild female mallards. Specifically, we tested the assumption that longer processing, surgery, and holding times have no effect on postsurgical survival, dispersal or site fidelity, breeding propensity (i.e., whether or not a female initiated at least one clutch), nest initiation date (i.e., day first egg was laid relative to start of breeding season), and first clutch size.

STUDY AREAS

During 2014–2015, we captured prebreeding mallards throughout 2 study areas in New Zealand. One site was located on the North Island, approximately 20 km south of Hamilton in the Waikato (WAI; 37°55′S, 175°18′E) and another on the South Island, approximately 30 km north of Invercargill in Southland (SOU; 46°12′S, 168°20′E; Fig. 1). We baited 4–6 trap sites within each study area with corn or barley from 6 weeks prior to trapping through to completion of trapping (range = 5–19 days), during which time traps were rebaited every 1–3 days. Study area boundaries differed by site and year (SOU$_{2014}$ = 3,000 ha; SOU$_{2015}$ = 4,900 ha; WAI$_{2014}$ = 25,800 ha; WAI$_{2015}$ = 19,200 ha) because of land-owner permission, trap locations, and bird movement.
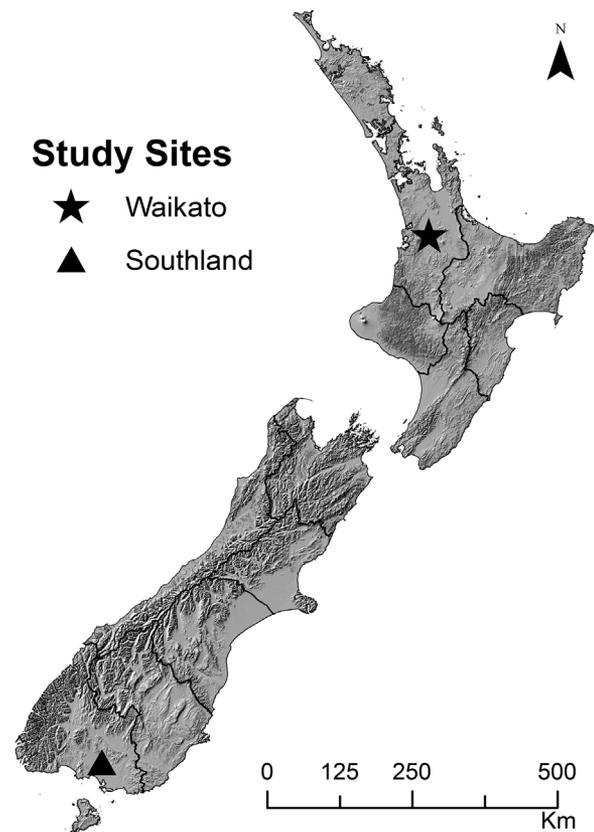
Figure 1. Map of study sites in New Zealand, 2014–2015, delineating New Zealand Fish and Game management unit boundaries, where we studied handling and marking effects on mallard and mallard–grey duck hybrids equipped with fully encapsulated abdominally implanted radiotransmitters.

METHODS

Field Methods

Capture, handling, and surgical procedures.—We trapped birds beginning in early-June in Waikato and early-July in Southland using baited funnel traps that we placed on the edge of refuge ponds (i.e., ponds that were not hunted during the most recent hunting season). Each year, we marked approximately 60 female mallards/study area and equipped them with a 22-g intra-abdominal very-high-frequency (VHF) radiotransmitter (Model IMP/150; Telonics, Mesa, AZ, USA; Rotella et al. 1993, Paquette et al. 1997). Transmitters were fully encapsulated (i.e., no percutaneous antenna), equipped with mortality sensors that were activated after 8 hr of inactivity, and programmed with a 12 hr on, 12 hr off (in 2014) or 14 hr on, 10 hr off (in 2015) duty cycle. Upon removal of birds from the trap, we recorded time of day and placed females in a communal holding pen to await processing and surgical implantation of transmitters. In Waikato, we processed birds near the trap locations and performed surgery under aseptic field conditions in a converted horse-trailer that served as a mobile surgery unit. In Southland, we transported birds <5 km before placing them in the holding pen; we performed surgical implantation under similar conditions in a converted sheep-shearing shed that served as a fixed-location surgery unit.

We defined "processing time" as the time elapsed from when we removed a bird from the holding pen until we placed it on the surgical table for implantation. During processing, we equipped all birds with a New Zealand Department of Conservation steel leg band and a colored auxiliary wrap-around band (in 2015 only), weighed them with electronic scales (± 1 g), and used a ruler to measure wing chord (± 1 mm) from the end of the carpometacarpus to the tip of the longest primary feather. With electronic calipers (± 0.1 mm,) we measured 1) head length from the back of the head to the tip of the bill; 2) culmen length (total length of the upper part of the bill); 3) tarsus length (i.e., length of the tarsometatarsal bone, excluding joints); and 4) keel length from the tracheal pit to the hind margin of the sternum. We classified female age as either second-year (SY) or after-second year (ASY) on cloaca and wing feather characteristics (Hochbaum 1942, Carney 1992). We collected the 2nd greater secondary covert feather for additional verification of age assignments (Krapu et al. 1979). We also collected 5–7 flank feathers and <3 mL of blood from each bird for related studies. Processing time depended on the number and experience of personnel, but could be confounded by the behavior of the bird (e.g., whether she struggled or remained calm), and time necessary to collect blood. Following processing, birds were handed to a 3- or 4-person surgical team who immediately began implantation surgery.

Protocols for surgical implantation followed Olsen et al. (1992) with the following exceptions: we used a C-Pram breathing circuit (SurgiVet; Smiths Medical PM, Inc., Norwell, MA, USA), a modified canine mask hooked to the anesthetic machine, and a 2.0-mm endotracheal tube for intubation. We placed the mask over the bird's bill and anesthesia was induced using isoflurane delivered at a flow rate of 4% until the bird appeared unconscious based on toe-pinch and wing extension reflexes ($\bar{x} = 4.6$ min, SD = 1.5). Once intubated, the anesthetist closely monitored breathing and heart rate using an esophageal audio-patient monitor and adjusted the flow of isoflurane when required (Korschgen et al. 1996); we used 70% isopropyl alcohol and Betadine® (7.5% w/v povidone–iodine) to soak the surgical area and CIDEX® OPA (0.55% Ortho-phthalal-dehyde; Advanced Sterilization Products, Irvine, CA, USA.) to cold-sterilize instruments and transmitters. We injected 0.2–0.4 mL of a local anesthetic (Marcain; 0.5% bupivacaine hydrochloride; AstraZeneca Ltd., Auckland, NZ) subcutaneously around the incision site between the posterior end of the sternum and the pubic bone (Korschgen et al. 1996). Immediately following intubation, we used a scalpel and tissue scissors to make a 2–3-cm incision in the skin layer, lifted the muscle layer with forceps before opening the coelomic cavity, and inserted the transmitter dextral to the liver (Korschgen et al. 1996). We closed the surgical site with a continuous suture pattern of 2 separate layers (subcutaneous muscle and tissue layer followed by skin layer) using absorbable monofilament suture and immediately administered pure oxygen following closure of the skin layer. Once birds became alert following surgery, they were placed in solitary holding pens for ≥45 min, after which they were released provided they were fully alert. Birds that were not fully alert after 45 min were checked every 10 min until they appeared ready for release (Korschgen et al. 1996). We recorded the time at 9 different stages of the surgical procedure: 1) when the mask went on and the administration of anesthesia began; 2) bird was deemed unconscious; 3) bird was intubated; 4) incision was made; 5) transmitter was fully inserted; 6) body wall was closed and tied-off; 7) skin layer was closed; 8) bird was extubated; and 9) bird was placed in a recovery pen.

The time from when the bird became unconscious after the placement of the mask to when the bird was extubated prior to regaining consciousness was considered "surgery time" and depended on the 1) speed at which a bird became unconscious, which could be an artifact of body mass, body condition, behavior (i.e., birds that appeared more agitated would often take longer to become anesthetized) or the experience of the anesthetist; 2) period it took the surgeon to implant the transmitter and tie the sutures; and 3) time it took for the bird to regain consciousness, which could be a result of the amount of isoflurane administered or individual attributes such as body size. We defined "holding time" as the time elapsed from when we checked traps and removed birds to the time the bird was finally released after surgical implantation. Holding time varied depending on the number of females captured and marked in a given day (range = 1–28), the state of those birds (i.e., excessively muddy birds were cleaned and dried prior to processing), and the order in which females were selected from the holding pen for processing.

Tracking and monitoring procedures.—The day following transmitter deployment, we began radiotracking birds to monitor survival and determine the onset of breeding and clutch size of the first detected nest attempt. We tracked females every 1–3 days using handheld telemetry or locations were triangulated using truck-mounted, null-array antenna systems (Kenward 1987) and Location of a Signal Software, Version 1.03 (Ecological Software Solutions LLC, Hegymagas, Hungary). If females went missing during ground-tracking, we searched for them extensively during road searches throughout the study area and beyond until they were relocated, or the nesting period had nearly completed (end of Nov). Additionally, during the peak breeding season, we conducted 1–3 aerial telemetry flights at each site by searching parallel transects up to 10 km outside of the study area boundary at an average height of 300 m above ground (Gilmer et al. 1981). We tracked females until they died, were not located within 10 km of the study area, or the transmitter no longer emitted a detectable signal.

Whenever a female was triangulated to the same location between consecutive tracking attempts, we approached the female on foot. To minimize disturbance and investigator-induced nest abandonment, we attempted to locate the nest without flushing the female, checked nests remotely every 1–7 days via telemetry, and visited nests directly only if the female was absent or if ≥1 week had passed since the last visit. Once the majority of birds had begun nesting (early Sep), we obtained a visual sighting of all remaining nonbreeding females weekly.

Mean age of nests at first visit was 15.4 days (SD = 9.0), which minimized the risk of investigator-induced abandonment (Howerter et al. 2014), but increased the probability that some nests may have been destroyed before we discovered them; however, apparent nest success was relatively high in our study areas (0.63; J. Sheppard, unpublished data), so few nests are likely to have failed before discovery. During each visit to the nest, eggs were counted and candled to determine stage of incubation (Weller 1956). We calculated nest initiation date as the date the first egg was laid based on the number of eggs and stage of incubation upon discovery, assuming a laying interval of 1 egg/day and absence of partial nest predation unless we noted evidence of egg fragments or egg shells. Procedures were approved under University of Auckland Animal Use Permit 001331.

Statistical Methods

Data preparation and censoring.—Approximately 10% (n = 26) of our marked birds went missing from our study sites during the prebreeding period, and we were unable to locate them despite numerous searches using truck-mounted and aerial telemetry throughout the study areas. Thus, we wanted to evaluate whether dispersal of these birds from the study areas was a result of capture or handling effects. To avoid confounding missing birds with birds that dispersed from the study site following nest failure, we defined the prebreeding period as the time from marking until onset of

nesting or until 95% of birds had initiated their first nest attempt in each site (90 days in Southland, 115 days in Waikato). We monitored frequencies of missing birds continuously during the postmarking and breeding seasons and defined a bird as missing if we were not able to detect a signal for ≥2 weeks (Esler et al. 2000b, Iverson et al. 2006). We included missing birds in analyses of dispersal and our calculations of body size and condition indices, but excluded them from analysis of breeding propensity. Of these 26 missing birds, we also excluded 11 from survival analysis because they went missing within 1 week of marking, thus we did not have sufficient data to model survival. We omitted an additional 11 birds from analysis of breeding propensity—2 that we were unable to track because of our restricted access to private land and 9 that died before they had an opportunity to nest (i.e., mortality occurred before the majority of birds had initiated their first nest attempt). We excluded an additional 7 birds from analyses of processing time because the time at which they were removed from the holding pen was not recorded. Finally, 1 bird was euthanized because it failed to fly away after surgery and we removed it from all analysis.

Statistical analysis.—We examined daily survival of birds prior to nesting (i.e., from capture to 30 days postmarking), seasonal dispersal, breeding propensity, Julian nest initiation date (range = 196–297, whereby 196 = 15 Jul), and initial clutch size (CLUTCH; range = 6–17 eggs) as response variables in generalized linear mixed models using binomial (logit link: survival, dispersal, breeding propensity) or Gaussian (identity link: nest initiation date, clutch size) distributions. Although processing and surgery time were components of total holding time, holding and surgery time were negatively correlated (Pearson's: $r = -0.32$, $P < 0.001$) and processing time was not correlated with holding or surgery time (Pearson's: $r = 0.002$, $P = 0.72$; $r = -0.007$, $P = 0.92$, respectively), so we treated all 3 measures as independent predictor variables. We estimated daily female survival from the date trapped to 30 days postmarking using logistic regression where we treated the number of days a bird lived (i.e., successes) relative to the number of days monitored (i.e., trials) as a binomial response variable (Arnold et al. 2012). Capture date differed depending on site, year, weather, and trap locations within each study site. To allow for the possibility that individuals captured on the same day may have been similarly affected by these or other unmeasured factors, we considered each trap date in each year to be a separate event (TRAP EVENT) and included this as a random effect in all analyses.

Individual female attributes often have a pronounced effect on initiation date and clutch size (Krapu et al. 2004, Devries et al. 2008). Consequently, subtle effects of capture and handling times could be masked by more pronounced variation in female quality. Thus, we incorporated female attributes (i.e., age class, body condition, body size), trap date, study area, year, and an interaction between study area and year as covariates in all models except for survival analyses where we removed site effects because there were no reported mortalities in Waikato during the first 30 days

following capture. For analyses of clutch size, we included nest initiation date as a covariate because clutch size in North American mallards decreases throughout the breeding season (Devries et al. 2008), and we anticipated a similar effect in New Zealand. We defined body size as the first eigenvalue of a principal component analysis using wing, keel, and head length measurements. All variables had positive factor loadings (wing = 0.54; keel = 0.56; head = 0.62), and PC1 explained 57% (SD = 1.30) of the variation among the 3 measurements. We regressed log body mass on PC1 and used residuals from the resulting equation (predicted log(mass) = $7.00 + 0.045 \times PC1$; $r^2 = 0.43$) as an index of body condition (Devries et al. 2008, Arnold et al. 2010).

For each response variable, we evaluated 3 models that incorporated the 3 measures of processing, surgery, and holding times separately. Distributions were right-skewed, so we used the $\log_e$-transformation of processing, surgery, and holding time in each model, and back-transformed estimates when presenting results. We plotted model-based estimates of response variables using the mean value of covariates and excluded 5% of observations from the right tail of the distribution so that relationships would not be driven by extreme outliers (Arnold et al. 2012). To assess their effects on response variables, we examined regression coefficients (β, SE) for processing, surgery, and holding times and concluded they had a significant effect if their 95% confidence intervals excluded 0. We completed analyses using PROC GLIMMIX in SAS® software, Version 9.4 (SAS Institute, Inc., Cary, NC, USA).

RESULTS

We radiomarked 243 female mallards (137 SY yearlings, 106 ASY) between 4 June and 7 July 2014–2015 (SOU_{2014}: $\bar{x} = 5$ Jul, SD = 2.6 days; SOU_{2015}: $\bar{x} = 2$ Jul, SD = 1.3; WAI_{2014}: $\bar{x} = 7$ Jun, SD = 5.5; WAI_{2015}: $\bar{x} = 6$ Jun, SD = 4.0). The average processing, surgery, and holding times were 18.2 min (SD = 5.3, range = 7.4–41.0), 21.2 min (SD = 5.9, range = 12.0–44.4), and 300.3 min (SD = 180.4, range = 89.0–1,663.0), respectively. Processing and surgery times were 1–4 min shorter, and total handling times were approximately 100 min longer in Southland versus Waikato, and similar-sized differences occurred between years (Table 1). During the 30-day period postmarking, 3 birds died within 2 days of marking: 1 bird was killed by a predator following a normal surgery and release; 1 bird had a deformed keel, which resulted in the transmitter being inserted lower than normal, exhibited labored flight upon release, and was subsequently killed by a predator; 1 was extremely muddy and wet upon capture, was lethargic upon release, and postmortem examination suggested the bird had died from hypothermia. Of the remaining 2 females that died, 1 female was killed by a mammalian predator 9 days postmarking and 1 was shot during the ongoing hunting season 15 days postmarking. We found no effect of processing, surgery, or holding time on female survival, dispersal, breeding propensity, initiation date, or clutch size of the first detected nest attempt (Table 2; Fig. 2).

Table 1. Estimates (mean ± SD) of processing, surgery, and holding times for each site (SOU = Southland, WAI = Waikato) and year for female mallards captured and equipped with fully encapsulated abdominally implanted radiotransmitters in New Zealand, 2014–2015.

Variable	n	Processing time $\bar{x}$	Processing time SD	Surgery time $\bar{x}$	Surgery time SD	Holding time $\bar{x}$	Holding time SD
Site							
SOU	122	17.5	4.9	19.4	5.3	346.5	220.9
WAI	109	19.3	5.7	23.2	5.8	243.6	105.7
t		−2.51		−5.24		4.43	
P		0.01		<0.001		<0.001	
Year							
2014	114	17.2	5.6	22.0	0.5	271.4	125.1
2015	117	19.4	4.9	20.4	6.6	323.9	223.4
t		−3.30		2.13		2.17	
P		0.001		0.04		0.03	

DISCUSSION

Despite the reputable advantages of abdominal-implant transmitters (Rotella et al. 1993, Dzus and Clark 1996, Paquette et al. 1997), few researchers have evaluated the variations of capture and handling duration during transmitter attachment on subsequent vital rates of birds. Our results suggest that additional processing, surgery, and holding times associated with implant transmitters did not affect survival, breeding propensity, initiation date, or clutch size of female mallards; thus, we have no indication that any measure of breeding ecology was compromised by our capture and handling methods. Additionally, the quantity of data collected was not influenced by marking techniques because we found no pronounced effect of prolonged processing, surgery, or holding times on dispersal probability.

We found no demonstrable effect of holding or handling times on female survival to 30 days postmarking. Although mortality may have been greater during the first 2 days postrelease (3 of 6 birds died during this period), it was unrelated to processing, surgery, or holding times. We attributed one of these deaths to hypothermia as a result of becoming wet and muddy in the bait trap (we censored another bird that died under similar conditions in 2015), and

Table 2. Regression coefficients (β) and standard errors (SE) derived from models evaluating effects of processing, surgery, and holding times on breeding propensity, dispersal, survival, initiation date, and clutch size, of mallards from study sites in New Zealand, 2014–2015.

Response variable[a]	Processing β	Processing SE	Surgery β	Surgery SE	Holding β	Holding SE
Female survival	−2.22	1.77	−0.62	2.00	−0.04	0.82
Dispersal	−0.59	0.77	−0.53	1.08	0.68	0.48
Breeding propensity	0.03	0.10	0.08	1.27	−0.28	0.51
Initiation date	−5.58	5.05	−7.98	6.58	−2.98	2.72
Clutch size[b]	−0.56	0.55	−0.15	0.73	0.25	0.29

[a] All models include intercept, female age, body condition, body size, trap date, site, year, an interaction between site and year, and a random effect of trap date.
[b] Models evaluating clutch size also included nest initiation date as a covariate.
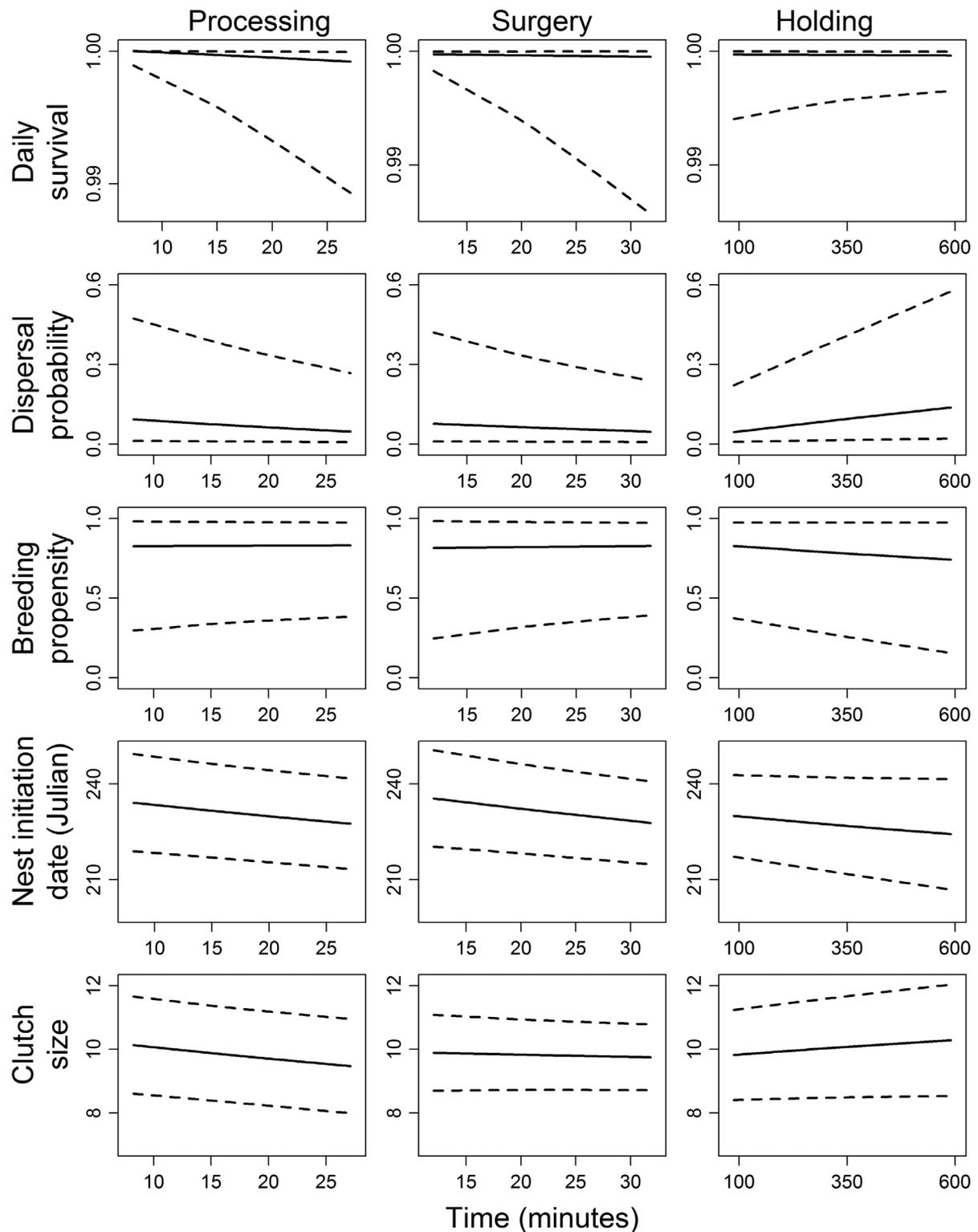
Figure 2. Predicted effects of processing, surgery, and holding time (min) on daily female survival, dispersal probability, breeding propensity, nest initiation date, and clutch size of first detected nest of female mallards in New Zealand, 2014–2015. Estimates were derived using mean covariates for adult females in Waikato study site in 2015. Dashed lines represent 95% confidence intervals.

another bird had an obvious deformity; we should not have radiomarked birds that had physical deformities or were excessively wet and muddy upon capture. We therefore recommend that researchers implement a postrelease interval before measuring survival. Short-term effects of prolonged

processing and holding times have been reported to decrease survival of pin-tailed sandgrouse (*Pterocles alchata*) and increase capture myopathy while limiting mobility functions of little bustards (*Tetrax tetrax*; Ponjoan et al. 2008, Casas et al. 2015). Additionally, Cox and Afton (1998) found that

the short-term survival of female northern pintail (*Anas acuta*) decreased when large numbers of waterfowl were captured concurrently, which subsequently increased holding times, but they did not detect an effect on survival when smaller numbers of birds (≤172) were captured. In our study, we did not exceed 95 birds/trap event. Aside from Olsen et al. (1992) who reported 18–24-hr holding time for canvasbacks (*Aythya valisineria*), average holding time of birds in this study surpassed mean holding times reported by other researchers (Nicholson et al. 2000, Ponjoan et al. 2008). For instance, Mulcahy et al. (2011) reported average holding times of 151.4 ± 60.4 min from capture to release of abdominally implanted bar-tailed godwits (*Limosa lapponica*), which is approximately half of our average holding time. We prebaited at our trapping sites; therefore, birds in our study had access to supplementary food for up to 6 weeks prior to capture and this may have increased condition and subsequent survival rates. Whether trap methods that provide access to supplemental food sources affect survival and reproduction is unknown, but should be investigated.

Generally, few data are gleaned from VHF-marked birds that disperse or are untrackable, and this may require researchers to mark additional individuals to obtain sufficient data, which opposes the ethical goal of sample size reduction for animals used in research (Animal Behaviour 2015). Although holding times employed here exceeded that of similar studies, we found no adverse effect on dispersal rates. In New Zealand, mallards tend to be nonmigratory, yet 14% of band recoveries collected in May–June (prebreeding) indicate movements of >50 km from birds marked at banding sites during postbreeding or molting in January and February (McDougall 2012). The maximum distance from our banding sites to study area boundaries was 15 km and aerial flights expanded up to 10 km beyond the boundary; thus, our maximum tracking range only covered a 25-km radius from banding sites. Even though little is known about dispersal and movement between the prebreeding and nesting stages, from band recovery data we expected that, by chance, some birds would disperse beyond our tracking capabilities.

The long-term effects of surgical time are not widely discussed in the literature and surgical times in this study were on par with times reported by Olsen et al. (1992; 18.2 min) and Mulcahy et al. (2011; 25 min). Although our results indicate that researchers need not worry about the amount of time a bird is under anesthesia during abdominal-implant procedures, we recommend that future researchers monitor and record surgical times to make sure they are consistent with previous studies. On average, processing time in this study was less than processing times reported for little bustards (Ponjoan et al. 2008), but nearly twice as long as processing times of least terns (*Sternula antillarum*) and snowy plovers (*Charadrius nivosus*; Hill and Talent 1990). Although prolonged processing times did not affect the parameters we measured in this study, we strongly encourage other researchers to minimize processing times and reduce unnecessary stress to birds by collecting only the most relevant data.

Overall, our results support previous research that techniques using fully encapsulated abdominal-implant radiotransmitters are suitable to enable researchers to obtain reliable estimates of reproductive performance and survival (e.g., Rotella et al. 1993, Dzus and Clark 1996, Korschgen et al. 1996, Paquette et al. 1997, White et al. 2013*b*). Furthermore, our results support the notion that capture and handling effects should be quantified in wildlife studies (Barron et al. 2010, McMahon et al. 2011), specifically when outcomes will be used to inform conservation and management decisions.

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Associate Editor: Stafford.