The Wilson Journal of Ornithology

ISSN: 1559-4491 (Print) 1938-5447 (Online) Journal homepage: www.tandfonline.com/journals/uwjo20

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To cite this article: Cheyenne R. Beach, Jennifer A. H. Koop & Auriel M. V. Fournier (28 Aug 2025): Effects of surgically implanted intra-abdominal transmitters with external antennae on egg laying and behavior of captive-reared Lesser Scaup (*Aythya affinis*), The Wilson Journal of Ornithology, DOI: 10.1080/15594491.2025.2538257

To link to this article: https://doi.org/10.1080/15594491.2025.2538257

Published online: 28 Aug 2025.

THE WILSON JOURNAL OF ORNITHOLOGY
https://doi.org/10.1080/15594491.2025.2538257

Effects of surgically implanted intra-abdominal transmitters with external antennae on egg laying and behavior of captive-reared Lesser Scaup (*Aythya affinis*)

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ABSTRACT

In preparation for a study on the migration behaviors and breeding success of Lesser Scaup (*Aythya affinis*), we evaluated the effects of surgically implanted intra-abdominal transmitters with external antennae on the reproductive capabilities and behaviors of captive-reared female Lesser Scaup in a captive setting. We surgically implanted transmitters in 10 of 17 female Lesser Scaup available at Pinola Aviary, Louisiana, USA. We randomly selected adult female individuals from two age categories to receive transmitters, and the remainder were assigned to the control group. After surgeries and recovery, we monitored breeding and nesting daily for 101 days, and we conducted daily, 10 min focal observations to compare preening, diving, resting, and feeding behaviors between birds with transmitters and control birds. Five of ten (50%) birds with transmitters and three of seven (43%) birds in the control group laid eggs. Several eggs from both groups were incubated by the aviary and successfully hatched. We found that control birds and birds with transmitters preened a similar amount during the pre-nesting period, but control birds reduced preening during the nesting period whereas those with transmitters did not. We did not find transmitter related effects on diving, resting, or feeding behaviors. Overall, we found that captive-reared female Lesser Scaup with intra-abdominal transmitters with external antennae can lay viable eggs and experience minimal alteration to their behavior, though more work is needed to evaluate whether differences in preening behaviors observed in captivity lead to meaningful impacts on body condition or reproduction in the wild.

KEYWORDS

Aythya affinis; feeding behavior; intra-abdominal transmitter; Lesser Scaup; preening behavior; surgical implants; transmitter effects

PALABRAS CLAVE

Aythya affinis; comportamiento de acicalarse; comportamiento de alimentarse; efectos de los transmisores; implantes quirúrgicos; Porrón Bola; transmisor intraabdominal

Efectos de la implantación quirúrgica de transmisores intraabdominales con antenas externas sobre la puesta de huevos y el comportamiento del pato *Aythya affinis* en cautiverio

RESUMEN

Como preparación para un estudio sobre los comportamientos migratorios y el éxito reproductivo del pato *Aythya affinis*, evaluamos los efectos de los transmisores intraabdominales

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Editor-in-Chief: K. L. Cockle

implantados quirúrgicamente con antenas externas sobre las capacidades reproductivas y los comportamientos de hembras criadas en cautividad. Se implantaron transmisores quirúrgicamente en 10 de las 17 hembras disponibles en Pinola Aviary, Louisiana, EE.UU. Seleccionamos aleatoriamente hembras adultas de dos categorías de edad para que recibieran los transmisores, y el resto se asignó al grupo de control. Tras las intervenciones quirúrgicas y la recuperación, realizamos un seguimiento diario de la reproducción y la nidificación durante 101 días, así como observaciones focales diarias de 10 minutos para comparar los comportamientos de acicalamiento, zambullida, descanso y alimentación entre las aves con transmisores y las aves del grupo control. Cinco de diez (50%) aves con transmisores y tres de siete (43%) aves del grupo de control pusieron huevos. Varios huevos de ambos grupos fueron incubados por el aviario y eclosionaron con éxito. Se observó que las aves de control y las aves con transmisores se acicalaron con una frecuencia similar durante el periodo previo a la nidificación, pero las aves del grupo control redujeron el acicalamiento durante el periodo de nidificación, mientras que las aves con transmisores no lo hicieron. No observamos efectos relacionados con el transmisor en los comportamientos de zambullida, descanso o alimentación. En general, encontramos que en cautiverio las hembras de *Aythya affinis* con transmisores intraabdominales con antenas externas pueden poner huevos viables y experimentar pocas alteraciones en su comportamiento, aunque se necesita más trabajo para evaluar si las diferencias en los comportamientos de acicalamiento que observamos en cautiverio se relacionan con impactos significativos en la condición corporal o la reproducción en la naturaleza.

Researchers have used external transmitters attached to birds to learn about natural history and ecology for over 60 years (Lord et al. 1962; Geen et al. 2019). Devices such as radio and satellite transmitters, geolocators, Global Positioning System (GPS) loggers, and GPS/Global System for Mobile Communications (GSM) transmitters have revolutionized our ability to study fine-scale movement patterns and behaviors. These devices have also given researchers the ability to identify critical habitat areas that encompass the full annual ranges of birds (McGowan et al. 2017; Casazza et al. 2020; McDuie et al. 2022; Gould et al. 2024). While these types of transmitters have been used with a wider array of species, they are not without tradeoffs. Transmitters add mass to an individual bird, which can negatively impact the bird's movements, behavior, survival, and reproduction (Perry 1981; Amundson and Arnold 2010; Lameris and Kleyheeg 2017; Geen et al. 2019). The attachment method, such as using a body harness system, leg band, or neckband attachment could impede the natural movement of the bird and could call into question whether observations mirror natural behaviors (Obrecht et al. 1988; Latty et al. 2010; Pennycuick et al. 2012; Enstipp et al. 2015; Lameris and Kleyheeg 2017; Lameris et al. 2018).

In response to these potential trade-offs and with the development of additional technologies, internal transmitters, which are placed within the body cavity of the bird, were developed and have been used for over 40 years (Korschgen et al. 1984, 1996; Olsen et al. 1992; Hepp et al. 2002). Internal transmitters are especially preferred with bird species such as diving ducks, because external transmitters are known to interfere with their ability to effectively dive for food (Korschgen et al. 1984; Olsen et al. 1992; Latty et al. 2010; Finger et al. 2016; Mezebish et al. 2022; Hall et al. 2024). While this type of transmitter has been used to study diving duck feeding behavior (Custer et al. 1996), environmental influences on spring migration (Finger et al. 2016), and migratory chronology and routes (Hall et al. 2024), relatively few studies have exclusively looked at internal transmitter effects on diving duck reproductive abilities (Olsen et al. 1992; Guillemette et al. 2002; Latty et al. 2010; Fast et al. 2011, and reviewed by Geen et al. 2019).

Internal transmitters are invasive in that they usually require surgical implantation under anesthesia, followed by a recovery period. For many models, an external antenna protrudes through the epidermis of the bird, requiring additional wound healing during recovery. The resulting displacement within the abdomen of internal transmitters may impede birds' ability to produce naturally shaped eggs, as has been shown in non-duck species, and this change in shape could impact fertility (Hooijmeijer et al. 2014). In addition, internal transmitters may cause discomfort that could alter the frequency of certain behaviors such as preening or feeding. The effects of abdominally implanted transmitters have been studied in Mallards (*Anas platyrhynchos*, Paquette et al. 1997; Machin 2002; Sheppard et al. 2017), eiders (Latty et al. 2010; Fast et al. 2011), and geese (Hupp et al. 2006), but many diving ducks are smaller than the studied species. Therefore, to ensure the impacts, if any, would not invalidate the results of future study, further work is needed to assess the impacts of these types of transmitters on reproduction and behavior of diving ducks (Korschgen et al. 1984; Olsen et al. 1992).

Here, we investigate the effects of surgically implanted intra-abdominal transmitters with external antennae on a common diving duck in North America, the Lesser Scaup (*Aythya affinis*). Lesser Scaup are medium-sized diving ducks that feed on aquatic invertebrates, plants, and seeds, often diving to gain access to food. Populations of Lesser Scaup have declined substantially from the 1960s, such that they are under a restrictive hunting season in the USA (i.e., limited hunting dates and bag limits; U.S. Fish and Wildlife Service 2024). Multiple factors may have contributed to this decline including contaminants, habitat loss, and changes to food resources (Austin et al. 2000; Afton and Anderson 2001). One potential contributor to population decline that remains to be tested is infection by invasive trematodes parasites, now common at Lesser Scaup migratory stopover locations, which may have carryover effects that reduce reproductive success (Beach 2021). In preparation for further studies investigating the impacts of trematode infections on Lesser Scaup reproductive success, we set out to validate the use of intra-abdominal transmitters with external antennae as a tool for these types of studies. To do so, we first aimed to quantify the effects of internal transmitters with external antennae on Lesser Scaup reproductive ability and behavior in a captive setting. Under these controlled conditions, we implanted transmitters and monitored (1) the ability of captive Lesser Scaup to breed and lay eggs and (2) the frequency of their behaviors, including preening, diving, feeding, and time spent on the water, in comparison to a control group without transmitters. The results serve as a first step in validating the use of internal transmitters in future studies with Lesser Scaup.

Methods

Study area

We conducted research at Pinola Aviary in Shreveport, Louisiana, USA, between February and May 2022. Pinola Aviary is a private aviary accredited by the Association of Zoos and Aquariums. Captive-reared Lesser Scaup were housed in two permanent enclosures (outdoor aviaries): 1) containing only male and female Lesser Scaup and approximately 14 m × 5 m in size, and 2) containing a mixture of North American waterfowl species and approximately 35 m × 6 m in size. Both enclosures contained approximately equal proportions of upland structures (a mixture of gravel, grass, shrubs, and trees) and artificial pond areas. Food was available *ad libitum* in open containers placed at the edge of the pond areas daily. The pond areas ranged in depth from 0 to 1.5 m.

Captive population

Seventeen captive-reared female Lesser Scaup were available in the captive population at Pinola Aviary. Seven after-second-year females had bred previously and the remainder were second-year birds that had hatched the previous year.

On 7 February 2022, all individuals were captured, marked with unique plastic color leg bands, weighed, and evaluated for surgical candidacy. We evaluated each individual to ensure she met a minimum body weight (500 g) such that the transmitter would be less than 5% of her body mass (Mezebish et al. 2020; Fair et al. 2023). All 17 individuals met the weight requirements. Within age classes, we randomly assigned 4 after-second-year and 6 second year (SY) birds to receive transmitters (hereafter, "birds with transmitters"), and the remaining 3 after-SY birds and 4 SY birds were assigned to the control group and did not receive transmitters (hereafter, "control birds"). The weight of birds with transmitters (mean ± SE = 705.5 ± 14.5 g) was similar to control birds (695.0 ± 23.1 g). All birds were returned to the enclosure they came from, resulting in 5 birds with transmitters in the first enclosure, 5 in the second enclosure, and 2 control birds in the first enclosure and 5 in the second enclosure. Intra-abdominal transmitters with external antennae were surgically implanted into the coelomic cavity dorsally and to the right of the ventriculus by a trained veterinarian on 8 and 9 February 2022, following standard surgical procedures (Olsen et al. 1992). Between the lower rib and pelvis, a puncture site was established dorsally and to the right of the ventriculus to allow the antenna of the transmitter to exit and stay outside of the body. Four after-SY birds and 1 SY bird received active, functional 25-g Global Positioning System-Global System for Mobile Communications (GPS-GSM) transmitters (OrniTrack-I25 4 G; Ornitela, UAB, Vilnius, Lithuania), and the remaining 5 SY birds received non-functional units. Nonfunctional units were created by the manufacturer and had the same mass and dimensions as the functional transmitters (46 × 22 × 24 mm with a flexible, 12 cm long antenna). Each surgery lasted approximately 25 min, and the time under anesthesia did not exceed 60 min. We released all individuals into their enclosures following a 3-h recovery period after surgery.

We implanted transmitters into captive-reared Lesser Scaup before they began laying eggs (approximately 8 weeks prior to laying) to allow the study individuals to recover from the immediate effects of surgery before beginning their reproductive efforts and to mimic what we plan to do in our field studies. While only birds receiving transmitters were subjected to surgical procedures, all birds (both with transmitters and control) were pulled, handled, and weighed the day prior to treatment.

Behavioral observations

Six days after surgery, we began daily, 10 min focal observations (hereafter, surveys) of the captive Lesser Scaup to count the frequency of behaviors (preening, diving, feeding, and resting) using the procedures outlined in Kesler et al. (2014). If a bird did a behavior not included in those categories the behavior was not included in the analysis. Time spent flying or frequency of flight were not measured because most individuals had clipped or pinned wings, per aviary protocol. All surveys were conducted in the morning. During the survey, the observer used binoculars to watch individuals and recorded their behaviors using a voice recording on a cell phone. A single behavior was counted from the time a bird's head was oriented forward, to when the bird's head returned to a forward position (Kesler et al. 2014). We also recorded the total number of minutes individuals spent on the water during the survey. Surveys were used to quantify any differences in behavior between birds with transmitters and control birds (Kesler et al. 2014). Surveys were conducted in strategic locations within the enclosures where the birds could be identified by unique leg band color and remain visible throughout the observation period without disturbance by the observer. A single observer (C. R. Beach) performed all surveys to avoid inter-observer biases. Two birds with transmitters and two control birds were surveyed daily, selected from a randomly ordered list, and were observed in a random order. When all birds had been surveyed once, the list repeated, and surveys continued daily. We concluded surveys for 101 days after surgery (20 May 2022), a similar duration of time compared to when we plan to study Lesser Scaup nest initiation in the wild (time from tagging during spring migration [~1 March] through the beginning of the nesting season [~mid-June]).

Nesting observations

Beginning 1 March 2022, we monitored individuals daily for breeding and nesting behavior (e.g., copulating, scouting, and use of nest boxes). Once nesting behavior began, trail cameras were set up in the nesting areas to identify nesting individuals and record laying. Although the nesting area was checked for additional eggs daily, there is a small possibility that some birds may have laid eggs that were missed given that not all areas of the enclosure were accessible during the course of our study.

Statistical analysis

To evaluate the differences in the counts of behaviors between birds with intra-abdominal transmitters and control birds, we fit a single model for each behavior (preening, diving, resting, feeding). We originally considered a generalized mixed-effects model with a Poisson response distribution and a log link function using the "lme4" package in R (R Development Core Team 2024, Version 4.1.2; Bates et al. 2015). But after testing for overdispersion and zero inflation using the DHARMa package (Hartig 2024, Version 0.4.7), we found our data for each behavior were overdispersed and zero-inflated; therefore, we ran a generalized mixed-effects model with a zero-inflated Poisson response distribution and a log link function using the "glmmTMB" package (Brooks et al. 2017, version 1.1.10). The response variable for each behavior model was the count of that behavior. The model for each behavior included an interaction between treatment group and reproductive period. We considered a relationship significant if the p-value was less than 0.05. We used bird ID as the random effect to account for individual differences.

To evaluate the difference in the proportion of time the birds with transmitters and control birds spent on the water during the 10 min surveys, we fit a single generalized mixed-effects model with a beta response distribution and a logit link function. The response variable was proportion of time spent on water during 10 min surveys, and the categorical predictor variables were treatment group, reproductive period, and their interaction. We included bird ID as a random effect to account for repeated observations on the same individuals. We chose a beta distribution because it is used for data that are a proportion or probability of one of two states (in our case the two states were on the water, or off the water, and the response variable was the proportion of time spent in the on-water state).

Results

Effects of transmitters on reproductive ability

Transmitters were not observed interfering with copulation, and interference with egg-laying appeared minimal. We observed 10 copulation events among birds with transmitters during behavioral observations, and copulation appeared to proceed normally, without interference from external antennae. The first Lesser Scaup egg in the enclosure was found on 19 April 2022 (69 days post surgery), and both control birds and birds with transmitters began laying eggs at this time. Five of 10 (50%) birds with transmitters (3 after-SY and 2 SY) and 3 of 7 (43%) control birds (2 after-SY and 1 SY) laid eggs. Anecdotally, some eggs from birds with transmitters appeared elongated compared to control birds. As per aviary protocol, all eggs were removed from nests shortly after laying, before incubation began, which prevented us from studying differences in clutch size. Eggs were removed because the aviary has a maximum size flock it can care for, and, therefore, not all eggs can be allowed to be incubated and hatched. A subset of eggs (including eggs from both treatment groups, and eggs which appeared normal and some which appeared elongated) were artificially incubated at the aviary. We do not know how many eggs of each shape, or in each category were incubated by the aviary. Based on reports from the aviary, eggs of both shapes and from birds in both treatment groups successfully hatched. Successful hatching confirmed that captive-reared female Lesser Scaup are capable of breeding and laying viable eggs after receiving an intra-abdominal transmitter with an external antenna.

Effects on behavior

We conducted 330 surveys (10 min focal observations) between 14 February 2022 and 20 May 2024, 165 surveys of control birds and 165 of birds with transmitters.

Treatment group and reproductive period had a significant interactive effect on preening behavior (b = 0.60, SE = 0.24, $P = 0.01$). Control birds and birds with transmitters preened a similar amount during the pre-nesting period, but during the nesting period birds with transmitters preened 18.5 ± 2.9 times ($n = 67$) during the 10 min observation compared to 11.0 ± 1.9 times ($n = 67$) for control birds (Fig. 1).

Treatment group and reproductive period did not have a significant interactive effect on diving behavior (b = −0.36, SE = 0.47, $P = 0.45$), nor did we find a difference in counts of diving behavior based on treatment group (b = 0.009, SE = 0.34, $P = 0.97$). We did find a difference based on reproductive period (b = 0.61, SE = 0.27, $P = 0.02$), such that, on average, pre-nesting birds dove 1.5 ± 0.3 times ($n = 196$) and nesting birds dove 2.2 ± 0.5 times ($n = 134$) during the 10 min observation.

Treatment group and reproductive period did not have a significant interactive effect on resting behavior (b = −0.11, SE = 0.45, $P = 0.80$). We did not find a difference in resting behavior based on treatment group (b = 0.06, SE = 0.35, $P = 0.85$) or reproductive period (b = 0.24, SE = 0.33, $P = 0.47$).

Treatment group and reproductive period did not have a significant interactive effect on feeding behavior (b = 0.11, SE = 0.54, $P = 0.82$). We did not find a difference in feeding behavior based on treatment group (b = −0.03, SE = 0.34, $P = 0.91$). We did find a difference in feeding behavior between reproductive periods, such that pre-nesting birds fed 6.0 ± 0.9 times ($n = 196$) and nesting birds fed 2.3 ± 0.5 times ($n = 134$) in the 10 min survey (b = −0.96, SE = 0.38, $P = 0.01$).

Treatment group and reproductive period did not have a significant interactive effect on time spent on water (b = −0.40, SE = 0.30, $P = 0.19$). We did not find a difference in time spent on water based on treatment group (b = −0.03, SE = 0.29, $P = 0.90$) nor reproductive period (b = 0.24, SE = 0.22, $P = 0.26$).

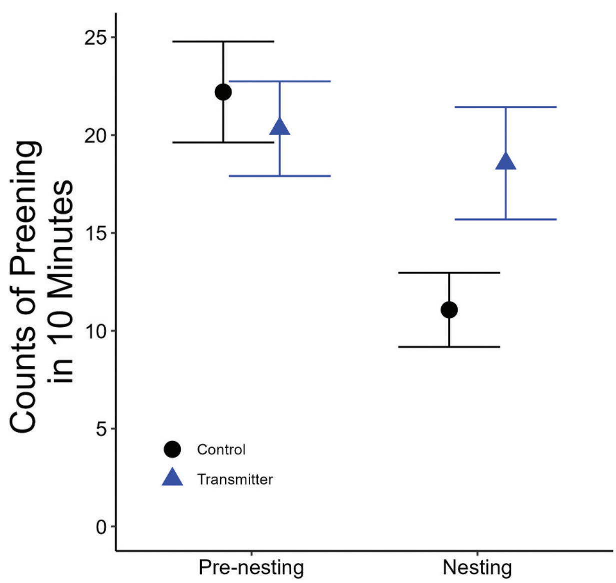

Figure 1. Comparison of counts of preening in captive-reared female Lesser Scaup (*Aythya affinis*) between individuals with intra-abdominal transmitters with external antennae and control birds and comparing birds during the pre-nesting and nesting periods. Error bars represent one standard error.

Discussion

A concern with using intra-abdominal transmitters with external antennae is that the antenna may inhibit breeding success by hindering copulation or the intra-abdominal transmitter may hinder the development and laying of viable eggs. Our study found that captive-reared female Lesser Scaup with intra-abdominal transmitters with external antennae were able to successfully copulate and lay viable eggs. More birds with transmitters (5 of 10 individuals) laid eggs than control birds (3 of 7 individuals), suggesting that transmitters did not inhibit their ability to reproduce, at least in captivity. Importantly, egg viability in our study was confirmed through artificial incubation and hatching but was not quantified, so it remains vital that future work investigate changes in nesting behavior post egg laying and reproductive success in captive or wild birds with transmitters. Our result is consistent with similar studies that found no effect of internal transmitters on reproduction in Mallards (Sheppard et al. 2017) and supports future work using these types of transmitters to evaluate questions around nest initiation and nest success.

The effects of intra-abdominal transmitters with external antennae on captive-reared Lesser Scaup behaviors are more varied and need to be interpreted with caution. Birds with transmitters preened a similar amount during the pre-nesting and nesting periods, while control birds decreased their preening during the nesting period. This result could indicate agitation or annoyance with the transmitter caused by copulation, egg development, or laying. Discomfort caused by the transmitters internally or by the external antennae could have elicited the additional preening behaviors. On average, birds with transmitters preened 68% more than control birds (7.5 additional times per 10 min survey). However, it is important to interpret the biological meaning of these results with some degree of caution, given the captive conditions in which the birds were studied. Preening may confer fitness benefits, but it is often done at the cost of other important behaviors such as feeding and vigilance (Redpath 1988). Birds at Pinola Aviary are fed from feeders placed on the shore, so feeding was less energetically expensive than for wild Lesser Scaup. The aviary is also protected from outside predators, which may reduce the need for vigilance behaviors. The captive setting was necessary for our initial study but should be considered a starting point for additional investigation on how transmitters affect preening behavior, and the fitness consequences for wild birds.

While captive studies may translate only partially to wild studies (reviewed by Palagi and Bergman 2021), captive studies are necessary for initially assessing transmitter effects because it can be logistically challenging to measure effects in a wild setting (Lameris and Kleyheeg 2017; Schummer et al. 2018). For example, Latty et al. (2010) used captive Common Eiders (*Somateria mollissima*) to assess the effects of internal transmitters on dive performance. Latty et al. (2010) recorded dives using strategically placed cameras in a dive column to quantify foot stroke number and behavior, something that would have been nearly impossible in a wild study. It is important to recognize that individuals in captive studies exist in an artificial environment where the pressures of a wild environment (e.g., food availability, predation, and exposure to environmental conditions) are minimized or removed, and captive individuals may therefore not react to experiments in the same way as their wild counterparts (Beach et al. 2024).

Our study adds to a growing literature assessing the impacts of transmitters on waterfowl breeding and behavior, which have mixed results. Several studies have found no transmitter effect, including on the migratory movements of dabbling ducks with external tags (Kesler et al. 2014), reproduction of dabbling ducks with external tags (Sheppard et al. 2017), and migratory timing of Lesser Scaup with internal transmitters with external antenna (Finger et al. 2016). A study across 13 species of waterfowl found adverse effects of transmitters in some species, including Lesser Scaup which had an increased risk of death with transmitter compared to those with only metal bands (Setash et al. 2024). Common Eider with internal transmitters with external antennae were found to have slower diving speeds, which could increase energy expenditures or force individuals with transmitters to use different habitat than birds without transmitters (Latty et al. 2010; Lameris and Kleyheeg 2017). Our study shows that intra-abdominal transmitters with external antennae did not impede the ability of Lesser Scaup to produce and lay eggs in captivity, but continued investigation of possible transmitter effects on wild Lesser Scaup reproduction and behavior should be a priority. In particular, as follow-up to our observations, we suggest that future studies consider effects on egg size, shape, and viability with natural incubation. These studies could use a quasi-control approach in which birds with transmitters are studied across multiple years to investigate short- and long-term transmitter effects (Lamb et al. 2020; Schreven et al. 2024).

Researchers must continue to consider their focal organisms' ecology, including habitat needs, behaviors, and species interactions, when choosing tracking methods to fit their study. Understanding, measuring, and reporting transmitter effects allows researchers to assess transmitter tolerance for their study species and study question. There is no single best method for remotely tracking birds. However, careful study to unveil the existence and types of transmitter effects on a given species is the first step toward robust methodologies using these tools (Lameris and Kleyheeg 2017; Geen et al. 2019; Setash et al. 2024).

Acknowledgments

We thank P. Dickson, J. Kraemer, and the veterinary and husbandry staff at the Pinola Aviary for their assistance and support. Special thanks to Scott Ford, Avian Specialty Veterinary Services, Milwaukee, WI, for surgically implanting all transmitters for this study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Funding was provided by the Federal Aid in Wildlife Restoration [W-43-R] fund administered by the Illinois Department of Natural Resources and the United States Fish and Wildlife Service.

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Data availability statement

The data that support the findings of this study are openly available in University of Illinois Urbana-Champaign Data Bank at https://doi.org/10.13012/B2IDB-4299781_V1.

Ethics statement

Work was conducted in compliance with Animal Care and Use Protocols LA22–0010 and 21-230 (Northern Illinois University and University of Illinois Urbana-Champaign).

Generative AI

The authors did not use AI in this work.

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