Notes

Evaluation of Light-Logging Geolocators to Study Mottled Duck Nesting Ecology

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Abstract

Geolocators are small devices that record and store time-stamped light levels that researchers typically use to approximate the latitude and longitude of small birds across the annual cycle. However, when geolocators are affixed to leg bands of larger-bodied birds, nest incubation by females interrupts the daily pattern of light and darkness. Thus, geolocators can provide information on nesting propensity, nest success, and renesting intensity; these demographic parameters are both difficult to measure unobtrusively and are critically important in determining population dynamics of birds, especially ducks. Here, we deployed 240 geolocators on mottled ducks *Anas fulvigula* in Louisiana and Texas in 2018–2019 to evaluate their utility in providing nesting data. During July 2018–January 2022, we recovered 16 geolocators from hunter-harvested birds, and learned of six other unreported recoveries, yielding a realized recovery rate of 7.1% (9.1% unrealized). Three of the recovered units provided breeding-season data. Two of these clearly indicated a single nest initiation in the early spring of 2019, and one of the units also logged an attempt in spring of 2020. Ducks incubated all three nests for approximately a month, suggesting that they all successfully hatched. The final geolocator logged five putative nest attempts over the course of 2 y. In 2019, both attempts were unsuccessful (incubated $\leq$ 10 d). In 2020, we documented three attempts spanning 20 February–10 June, all of which appeared to have failed. For all failed attempts, the hen left the nest at dusk or overnight and did not return, which is suggestive of mammalian predation. Geolocators successfully provided information on breeding-season activities of mottled ducks, and we documented renesting rates following nest depredation. However, we achieved a smaller sample size than anticipated (three usable returns), resulting in an effective cost of $11,800 per usable return. Where possible in other species, capturing birds immediately prior to the breeding season, and improvements to geolocator attachment have the potential to improve recovery rates and increase cost effectiveness of the technique.

Keywords: waterfowl; breeding; Louisiana; nesting propensity; nest success

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Introduction

The Western Gulf Coast (WGC) is home to more than 90% of the worldwide population of mottled ducks *Anas fulvigula* (Wilson 2007), a nonmigratory species that fulfills its needs within a relatively small geographic range (Moon et al. 2015). Breeding survey data indicate that the WGC mottled duck population has declined since 2008, particularly in Louisiana, where the population has dropped by approximately 50% over the past decade (Bonczek and Ringelman 2021). Because of its restricted geographic range and downward population trajectory, the U.S. Fish and Wildlife Service has identified the mottled duck as a focal species and it is a priority species in Texas and Louisiana state wildlife action plans (Connally 2012; Holcomb et al. 2015). Accordingly, WGC mottled ducks are the subject of strategic conservation efforts by agencies, nongovernmental organizations, and regional conservation partnerships (e.g., Gulf Coast Joint Venture [Wilson 2007]). These habitat conservation and management efforts are targeted to have the greatest net effect on the demographic rates that researchers believe drive mottled duck populations.

Previous studies have identified recruitment as a major limiting factor for mottled duck population growth (reviewed in Bonczek and Ringelman 2021). Indeed, Rigby and Haukos (2014) constructed a matrix population model for WGC mottled ducks and found that fertility had the largest effect on population growth ($r^2 = 0.675$), where nesting propensity ($r^2 = 0.322$) and nest success ($r^2 = 0.200$) were the most influential components. Across its native range (including peninsular Florida), prior studies have estimated mottled duck nesting propensity to span 15–77% (Finger et al. 2003; Dugger et al. 2010; Rigby and Haukos 2012; Varner et al. 2013), which is substantially lower than the 95–100% expected in adult mallards *Anas platyrhynchos* when conditions are favorable (Hoekman et al. 2002). As in mallards, female age, prior experience, and body condition likely determine nesting propensity (Devries et al. 2008). Additionally, there are likely strong trade-offs between it and adult survival, especially during drought conditions along the WGC (Johnson 2009; Rigby and Haukos 2012). Mottled duck nest survival ranges 5–57%, with many estimates below the 15% success rate (Bonczek and Ringelman 2021) that researchers believe to be necessary to maintain mallard populations (Cowardin et al. 1985). Mottled duck nesting propensity and nest survival are both logistically difficult to study in the vast coastal marshes that characterize the WGC landscape and typically require tracking telemetered hens to their nests, resulting in low sample sizes (Finger et al. 2003: $n = 56$ over 3 y; Rigby and Haukos 2012: $n = 39$ over 3 y) and the potential for deleterious transmitter effects on breeding ecology (Rotella et al. 1993; Paquette et al. 1997; Kesler et al. 2014).

Geolocators are small (0.5–3 g), unobtrusive, inexpensive ($150–200) devices that record and store time-stamped light-level data at regular intervals. After researchers recover the units, they can use light levels to interpret day length (latitude) and the timing of dawn and dusk (longitude) to estimate geographic position of the unit to an accuracy of hundreds of kilometers (Hill 1994; Bridge et al. 2013; Hallworth et al. 2015). When researchers mount geolocators on leg bands, the physical act of nest incubation interrupts regular daily rhythms of daylight, allowing the researcher to infer nesting activity from geolocator data (Burger et al. 2012; Gosbell et al. 2012; Weiser et al. 2016; Verhoeven et al. 2020). Because VHF or satellite transmitters provide superior positional data (Ringelman et al. 2015; Casazza et al. 2020), researchers rarely deploy geolocators on waterfowl to assess patterns of movement (Eichhorn et al. 2006; Solovyeva et al. 2012; Hanssen et al. 2016; Cook 2018; Cook et al. 2021; MacCallum et al. 2021), but there is an underrecognized potential to use geolocators to study waterfowl nesting ecology. Geolocators may be particularly useful for studying demographic rates like nesting propensity, given long-standing concerns about transmitter effects on waterfowl nesting rates (Rotella et al. 1993; Paquette et al. 1997). Cook (2018) pioneered the use of geolocators to study wood duck *Aix sponsa* nesting ecology and confirmed the accuracy of geolocator data to identify the number and timing of nesting attempts, as well as nest success (inferred using the onset of nesting and known incubation periods). However, it remains unclear how well leg-mounted geolocators would detect nesting attempts outside of a dark wood duck box or natural cavity (Cook 2018), including natural ground nests (Cook et al. 2021), although emerging evidence supports their value in detecting nesting attempts of ground-nesting harlequin ducks *Histrionicus histrionicus* (MacCallum et al. 2021).

Geolocators may provide a new opportunity to study WGC mottled duck nesting propensity and nest success—the two most important factors driving population dynamics—using minimally invasive methods. Here, we describe results from a pilot study where we deployed geolocators on WGC mottled ducks in Louisiana and Texas, with specific objectives to 1) quantify geolocator recovery rates from hunter harvest and routine annual banding operations, and 2) evaluate the effectiveness of geolocators for identifying mottled duck nesting attempts and nest success. The overarching goal was to determine the feasibility of a longer-term study using geolocators to estimate nesting propensity and nest success of mottled ducks across broad spatial and temporal scales, which could also inform its application to other waterfowl species with similar recovery rates.

Study Site

We selected four locations for geolocator deployment. In Louisiana, we focused our efforts solely on Rockefeller Wildlife Refuge (29°42′N, 92°52′W; hereafter Rockefeller) and adjacent private land in southwestern Louisiana. Rockefeller borders the Gulf of Mexico, extending inland $\sim$ 10 km, and contains both managed and unmanaged wetland units ranging from fresh to saline. In Texas, we focused efforts on Upper Texas Coast, Mid-Coast, and South Texas. In the Upper Texas Coast, we deployed geolocators on the Texas Chenier Plains National Wildlife Refuge Complex (Anahuac, McFadden, Texas Point, and Moody National Wildlife Refuges), J.D. Murphree Wildlife Management Area (29°51′N, 94°02′W), and neighboring private lands. In the Mid-Coast, we deployed geolocators on Mad Island Wildlife Management Area (28°41′N, 96°04′W) and multiple privately owned wetlands in Galveston, Brazoria, and Matagorda Counties. The Texas Mid-Coast properties were all inland of bays and contained managed and unmanaged marsh units from fresh to saline. In South Texas, we deployed geolocators on a large freshwater emergent marsh on private land in Kleberg County.

Methods

Our goal was to study the breeding ecology of mottled ducks, and under ideal circumstances we would deploy geolocators after the winter hunting season and before the onset of breeding. However, during late winter and early spring mottled ducks are widely dispersed, nongregarious, extremely wary of humans and novel objects, and do not respond to bait. Thus, they cannot be captured in large numbers using any traditional capture techniques, including walk-in or swim-in traps, rocket nets, or mist nets (K.M.R., unpublished data). Therefore, during new moon phases July–September 2018–2019, we captured flightless molting mottled ducks using spotlights and airboats in conjunction with annual preseason banding efforts conducted by the Louisiana Department of Wildlife and Fisheries and the Texas Parks and Wildlife Department. We banded captured females with a standard U.S. Geological Survey (USGS) aluminum or incoloy leg band (size 7A); we banded a subset of females on the other leg with a plastic band affixed with a geolocator. For geolocator units, we created custom-molded yellow plastic leg bands (Spinner Plastics, Inc., Springfield, IL) inscribed with researcher contact information. We molded plastic leg bands to fit mottled duck tarsi by heating and bending them around a standard 7/16-in. (11.11-mm) carriage bolt, overlapping the ends. We drilled a pair of holes, spaced approximately 6 mm apart, through the band and affixed a 1-g Intigeo-C65-COOL light-level recorder (Migrate Technology Ltd., Cambridge, United Kingdom) using a 2.2-mm-wide plastic cable tie with stainless steel barb (Grainger, Inc., Lake Forest, IL; Figure 1). We used Migrate Technology IntigeoIF v1.7 software to calibrate geolocators and programmed them to log the brightest light level recorded over 5-min intervals, translating to an anticipated lifespan of 24–30 mo. We released birds within 30 min near the point of capture. We conducted all work under federal banding permits 06669 and 06827. This project was exempt from Institutional Animal Care and Use Committee approval because no university personnel were involved in field work.

Figure 1. Intigeo-C65-COOL light-level geolocator (Migrate Technology) affixed to a custom-molded acrylic leg band with a zip tie; this unit was on a female mottled duck *Anas fulvigula* at Rockefeller Wildlife Refuge, Louisiana, in 2018.

When we recovered geolocators, either from hunters or during banding operations in subsequent years, we used an IntigeoIF interface (Migrate Technology) to download the time-stamped light-level data (.lux file type). We used the readMTlux and lightImage functions in the TwGeos package (Lisovski 2019) in program R (R Core Team 2018) to read and visualize log-transformed light-level data. Given the small number of geolocator recoveries that included breeding-season data, we did

Table 1. Summary of mottled duck *Anas fulvigula* geolocator deployment and recoveries in Louisiana and Texas by age class, July 2018–January 2022.

Deployment year	Location	Geolocators deployed			Geolocators recovered		
		L	HY	AHY	L	HY	AHY
2018	Louisiana	0	98	58	0	8[a]	4
	Texas	4	14	46	1	0	4
2019	Louisiana	0	10	10	0	0	0
Total		4	122	114	1	8[a]	8

L = local; HY = hatch year; AHY = after hatch year.

[a] One mottled duck was recovered as AHY bird on 16 November 2019.

not develop sophisticated statistical algorithms to detect nesting attempts (as per Cook 2018); instead, we visually inspected light-level plots and manually scoured the raw data to identify nesting attempts. Briefly, we used the light-level plots to identify an hour when the female was commonly on the nest, and then used a pivot table in Microsoft Excel to identify the earliest day where the 5-min averages of light levels during that hour were unusually low. We then manually reviewed data from that day backwards to identify any periods of laying before the onset of full-time incubation (Ringelman and Stupaczuk 2013; Croston et al. 2020), requiring a definitive dimming of the light logger in the morning as an indication of nesting activity. We determined nest termination as the day of incubation interruption followed by a transition to normal circadian daylight recording.

Results

In 2018, we deployed 220 total geolocators on mottled ducks, with the majority ($n = 156$) on Rockefeller Wildlife Refuge in Louisiana. Abundant rain and extensive wetland area in 2018 made capturing mottled ducks more difficult in Texas, limiting our deployments across a combination of federal, state, and private land capture sites to 14 geolocators in the Upper Texas Coast, 26 in the Texas Mid-Coast, and 14 in South Texas. We subsequently purchased an additional 20 geolocator units, all of which we deployed on Rockefeller Wildlife Refuge in summer 2019.

During July 2018–January 2022, we recovered 16 geolocators from hunter-harvested birds (Table 1), and recaptured 1 additional geolocator during banding operations at Rockefeller in July 2020, yielding a realized overall recovery rate of 7.1%. However, we learned by way of band reports to the USGS Bird Banding Lab that hunters harvested two additional mottled ducks originally marked with geolocators in 2018 in Louisiana during the 2019–2020 hunting season. We later learned through conversations with the hunters that harvested the birds that neither bird possessed a plastic band or geolocator at time of harvest. We became aware via social media posts and discussions with local hunters of at least two additional hunter-recovered geolocators that hunters did not report to us or to the USGS Bird Banding Lab. Finally, field personnel captured two geolocator-equipped birds during summer banding efforts in 2020 but mistakenly released them without attempting to recover data from the units. Accounting for tag loss and unreported or unrecovered units, our unrealized (i.e., potential) overall recovery rate was 9.6%.

We recovered 14 geolocators (and the two unreported by hunters during the hunting season immediately following deployment; these did not provide data from the breeding season. We recovered three geolocators with breeding-season data (1.25% usable recovery rate), and regrettably, both mottled ducks that lost the plastic band and the two recaptured during banding efforts would have logged ≥ 1 y of breeding-season data (2.9% unrealized usable recovery rate). All three of the mottled ducks for which we had breeding-season data undertook a nesting attempt in each season for which we had data; we acknowledge that our limited sample size precludes us from a rigorous evaluation of nesting propensity. For all attempts, we were able to identify laying periods (2–4 d) before the onset of full-time incubation, but presumably we missed several days of laying given the clutch size of mottled ducks (Baldassarre 2014), so the dates given here are late estimates of nest initiation. One duck initiated its nest on 25 March 2019, and given an incubation time of 24–28 d (Baldassarre 2014), we presume the nest hatched on 27 April 2019 (Figure 2). The second mottled duck for which we collected breeding-season data initiated two nests in consecutive years. The duck initiated the first nest on 6 February 2019 and eggs presumably hatched on 9 March 2019 (Figure 3). This duck initiated its second nest on 25 February 2020 and eggs presumably hatched on 26 March 2020 (Figure 3). The final mottled duck logged five putative nesting attempts, none of which were successful. The duck initiated its first nest on 20 February 2019 and it failed on 25 February (Figure 4). She renested on 29 March 2019, but that nest also failed 10 d later on 8 April. In 2020, we documented a probable nesting attempt on 7 March that failed on 13 March, and two clear nesting attempts that spanned 18 March–8 April and 24 May–10 June, both of which were also unsuccessful.

Discussion

The overall realized recovery rate for geolocators deployed on mottled ducks was low (7.1%), even when accounting for tag loss and unreported or unrecovered units (unrealized recovery rate = 9.6%), but commensurate to mottled ducks marked only with metal bands (5.0–11.1 direct recovery rate; Haukos 2015). Recovery rates for units with usable breeding-season data were even lower (1.25% realized and 2.9% unrealized). These rates are lower than the 12.9% overall recovery rate and 5.0% usable recovery rate that we anticipated based on prestudy simulations. It is possible that there was additional harvest and nonreporting that we did not detect, or if mottled duck survival rates have declined in recent years that would have led to an overestimate of recovery rates in our simulations. It is also possible that the yellow leg bands to which we affixed geolocators attracted aquatic predators beyond those attracted by a

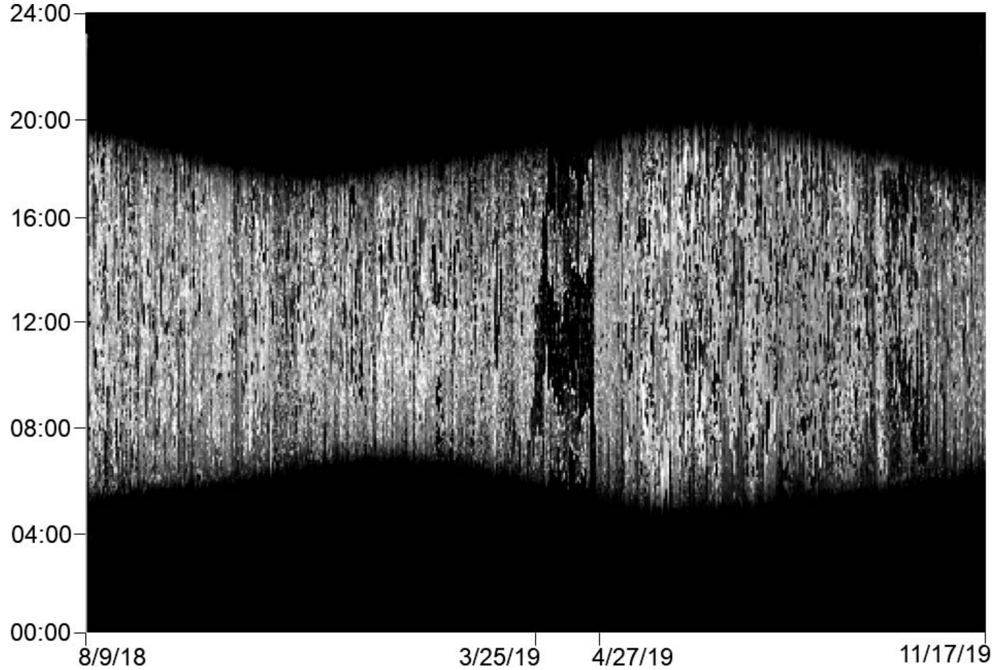

Figure 2. Geolocator light-level data for a mottled duck *Anas fulvigula* captured on Rockefeller Wildlife Refuge, Louisiana, on 9 August 2018. Dates shown represent deployment and recovery date, as well as a presumed successful nesting attempt in 2019. Times are Central Standard.

metal leg band, but we have no data to support or refute this hypothesis. Finally, Hurricane Barry passed over southwestern Louisiana in July 2019, hampering routine banding operations, altering habitat quality for the rest of the summer, and potentially causing substantial mottled duck mortality (Ringelman et al. 2021). Particularly vexing was our rate of tag loss, a factor better within researchers' ability to control. During the first night of deploying geolocators, it quickly became clear that the initial dimension of our customized plastic leg bands, which we based on the size of USGS leg bands typically attached to mottled ducks, was too large. Although we

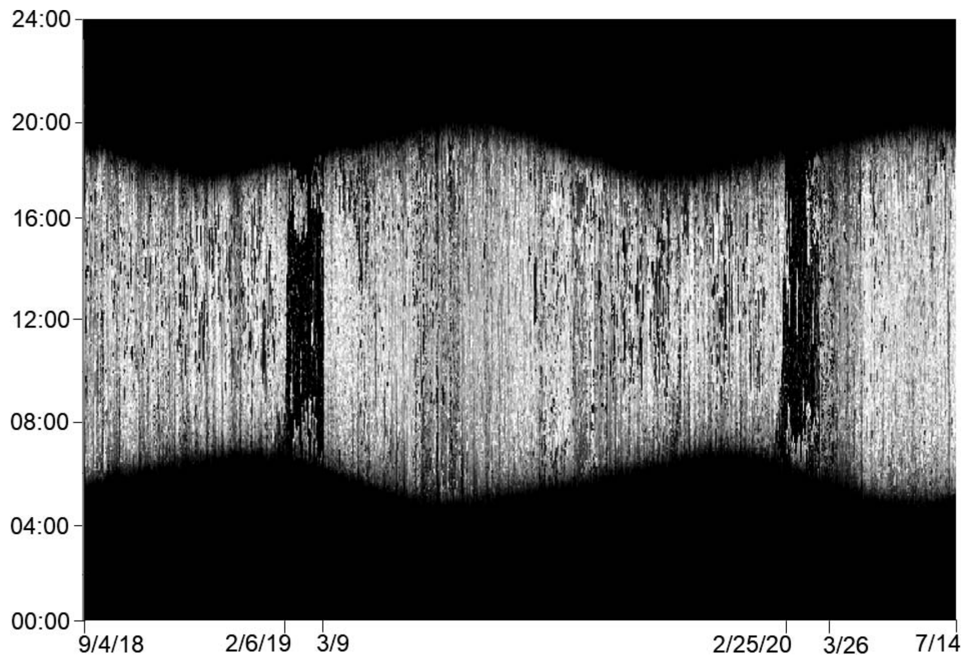

Figure 3. Geolocator light-level data for a mottled duck *Anas fulvigula* captured on Rockefeller Wildlife Refuge, Louisiana, on 4 September 2018. Dates shown represent deployment and recovery date, as well as two presumed successful nesting attempts in 2019 and 2020. Times are Central Standard.

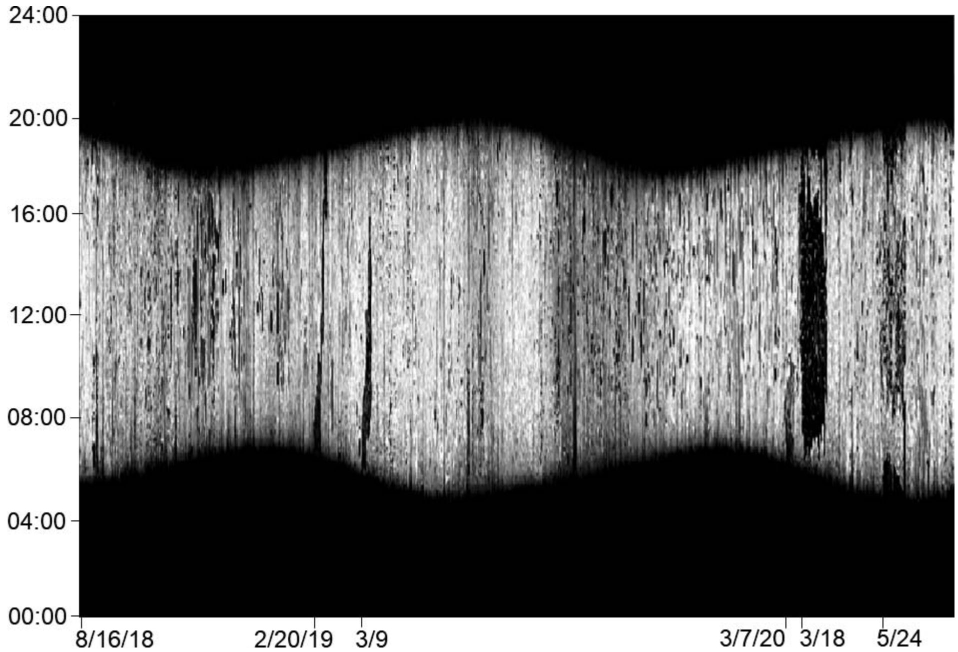

Figure 4. Geolocator light-level data for a mottled duck *Anas fulvigula* captured on Rockefeller Wildlife Refuge, Louisiana, on 16 August 2018. Figure shows deployment date along with initiation dates for five failed nesting attempts across 2019 and 2020. Times are Central Standard.

deployed only a handful of geolocators using bands with these initial dimensions, we later confirmed that one was lost from the mottled duck when the USGS received a report of the metal band. However, even after resizing the plastic band, we still documented at least one additional instance of band loss. We strongly recommend sealing the overlap portion of the plastic band with polyacrylamide glue to reduce the chances of loss.

Nesting propensity of mottled ducks is low and highly variable relative to closely related species (Bonczek and Ringelman 2021), and is thus of substantial interest to biologists. Each of the three geolocators that logged breeding-season data indicated a nesting attempt. The first two ducks logged nesting attempts that lasted approximately 1 mo, indicating that those nests likely hatched (Cook 2018; MacCallum et al. 2021), a supposition further supported by a lack of renesting attempts, because mottled ducks are known to be prolific renesters. Despite the fact that mottled ducks have a protracted breeding season, we did not document any attempts at a second clutch following an apparent successful first nest, the rarity of which is supported in the literature (Stutzenbaker 1988; Bonczek and Ringelman 2021). The third geolocator we recovered in January 2022 we believe logged at least five nesting attempts. Both attempts in 2019 were terminated quickly (after 5 and 10 d), and light-level data indicated the hen left the nest at dusk, and overnight (respectively), which is suggestive of a mammalian predation event (Croston et al. 2018). In 2020, we documented one probable, and two clear nesting attempts. The latter two were both terminated overnight after 21 and 17 d, respectively, which is also suggestive of mammalian predation. Data provided from this female indicate that mottled ducks will renest multiple times after nest failure, with internest intervals as short at 5 d and as long as 46 d. Because of the small sample sizes we attained in this study, simple statistical summaries completed by hand were sufficient for identifying nesting attempts. However, we would recommend using methods similar to those developed by Cook (2018) for identifying attempts for many individuals, as manually scouring the data is revealing, but time-consuming.

Our research verified the ability of light-logging geolocators to detect nesting attempts in a wild, ground-nesting dabbling duck, and there was little uncertainty in our data of determining the success or failure of those nests. Recovery rates in our study were within the range reported for metal leg bands, but nevertheless, the cost of deploying a large number of geolocators may preclude their use to study nesting ecology of ducks unless researchers can achieve greater recovery rates and sufficient sample sizes. The effective cost per recovered geolocator with usable breeding season data was $11,800. However, we deployed our geolocators during late-summer molt, such that birds had to survive an entire season (including the hunting period) before logging nesting data of interest. Our direct recovery rates indicate that researchers would achieve a much greater sample size if they deployed geolocators in late winter or early spring, although capturing some species of ducks (especially mottled ducks) is difficult during this time of year. Other options for increasing recovery rates include incentives for returning geolocators and more intensive recapture efforts in years during and 2–3 y after geolocator deployment. Geolocators may prove particularly valuable where philopatry to capture sites is high (as in some colonial-nesting birds), or when other research objectives are related to spatial and movement ecology.

Supplemental Material

Table S1. Raw light logger data collected from a Mottled Duck *Anas fulvigula* captured on Rockefeller Wildlife Refuge, Louisiana, USA in 2018 that shows nesting attempts.
Available: https://doi.org/10.3996/JFWM-22-014.S1 (6.177 MB CSV)

Table S2. Raw light logger data collected from a second mottled duck *Anas fulvigula* captured on Rockefeller Wildlife Refuge, Louisiana, in 2018 that shows nesting attempts.
Available: https://doi.org/10.3996/JFWM-22-014.S2 (8.987 MB CSV)

Table S3. Raw light logger data collected from a third mottled duck *Anas fulvigula* captured on Rockefeller Wildlife Refuge, Louisiana, in 2018 that shows nesting attempts.
Available: https://doi.org/10.3996/JFWM-22-014.S3 (7.570 MB CSV)

Reference S1. Connally W, editor. 2012. Texas conservation action plan 2012–2016: overview. Austin: Texas Parks and Wildlife Department.
Available: https://doi.org/10.3996/JFWM-22-014.S4 (872 KB PDF)

Reference S2. Holcomb SR, Bass AA, Reid CS, Seymour MA, Lorenz NF, Gregory BB, Javed SM, Balkum KF. 2015. Louisiana Wildlife Action Plan. Baton Rouge: Louisiana Department of Wildlife and Fisheries.
Available: https://doi.org/10.3996/JFWM-22-014.S5 (12.513 MB PDF)

Reference S3. Johnson FA. 2009. Variation in population growth rates of Mottled Ducks in Texas and Louisiana. Reston, Virginia: Report to the U.S. Fish and Wildlife Service, USGS Administrative Report.
Available: https://doi.org/10.3996/JFWM-22-014.S6 (417 KB PDF)

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