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RESEARCH ARTICLE

Geolocators on Golden-winged Warblers do not affect migratory ecology

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ABSTRACT

The use of light-level geolocators is increasingly common for connecting breeding and nonbreeding sites and identifying migration routes in birds. Until recently, the mass and size of geolocators precluded their use on songbird species weighing <12 g. Reducing the mass of geolocators, such as by shortening or eliminating the light stalk, may make their deployment on small birds feasible, but may also inhibit their ability to receive light reliably, because small geolocators can be shaded by feathers. Here we report geolocator effects on migratory ecology of Golden-winged Warblers (*Vermivora chrysoptera*) in Minnesota and Tennessee. We also evaluated whether stalk length influenced precision of location data for birds on the breeding grounds. At 8–10 g, Golden-winged Warblers are the smallest birds to be outfitted with geolocators to date. We found no differences in return rates, inter-annual territory fidelity, or body mass between geolocator-marked individuals and a control group of color-banded individuals. We observed no difference in return rates or variation in estimated breeding locations between birds marked with stalked geolocators and those with stalkless geolocators. Our results suggest that some small songbirds can be safely marked with geolocators. Light stalks appear to be unnecessary for Golden-winged Warblers; the added mass and drag of stalks can probably be eliminated on other small songbirds.

Keywords: geologger, geolocation, light stalk, songbird, *Vermivora chrysoptera*

Los geo-localizadores no afectan la ecología migratoria de *Vermivora chrysoptera*

RESUMEN

El uso de geo-localizadores con detectores de nivel de luz es cada vez más común para conectar los sitios reproductivos y no reproductivos y para identificar las rutas migratorias de las aves. Hasta hace poco, el peso y el tamaño de los geo-localizadores no permitía su uso en especies de aves canoras que pesaran <12 g. La reducción del peso de los geo-localizadores, mediante el acortamiento o la reducción de las varillas lumínicas, puede hacer que sea posible su colocación a pequeñas aves, pero también puede inhibir su capacidad para recibir la luz de modo confiable, debido a que los pequeños geo-localizadores pueden ser tapados por las plumas. Aquí describimos los efectos de los geo-localizadores en la ecología migratoria de *Vermivora chrysoptera* en Minnesota y Tennessee. También evaluamos si el largo de las varillas lumínicas influencia la precisión de los datos de localización de las aves en los sitios reproductivos. *V. chrysoptera* pesa entre 8 y 10 g, siendo hoy en día el ave más pequeña a quién puede colocarse un geo-localizador. No encontramos diferencias en las tasas de retorno, la fidelidad territorial inter-anual o el peso corporal entre individuos marcados con geo-localizadores y el grupo de individuos control marcados con anillos de colores. No observamos una diferencia en las tasas de retorno o en la variación en la estimación de las localidades reproductivas entre las aves marcadas con geo-localizadores con o sin varillas lumínicas. Nuestros resultados sugieren que algunas aves canoras pequeñas pueden ser marcadas de modo seguro con geo-localizadores. Las varillas lumínicas parecen ser innecesarias para *V. chrysoptera*; el peso adicional y la carga de las varillas pueden ser probablemente eliminados en otras aves canoras pequeñas.

Palabras clave: ave canora, geo-localizador, localización geográfica, varilla lumínica, *Vermivora chrysoptera*

INTRODUCTION

Many species of migrant songbirds are experiencing population declines (North American Bird Conservation Initiative 2009) and there is evidence that in some cases, population declines may not be related to conditions during the breeding season (Holmes 2007). To develop full life-cycle conservation strategies, it is important to identify wintering locations, migratory routes, and important stopover sites. Recent advances in technology have allowed many species' migrations to be tracked and nonbreeding locations to be identified for the first time. Satellite transmitters (e.g., Fuller et al. 1995) and GPS (Global Positioning System) transmitters (e.g., Bouten et al. 2012) are effective methods for accurately locating individuals nearly anywhere on the planet. However, these technologies require relatively large, heavy batteries to record and transmit location data in real time; the smallest currently available units are 1-g GPS transmitters that record 10 locations, but are currently unsuitable for smaller birds (i.e. <20 g).

Light-level geolocator technology (hereafter: geolocators) is an increasingly common method of identifying wintering locations of migratory songbirds (reviewed by McKinnon et al. 2013). Geolocators are archival data loggers that detect and record light. Once recovered, daily estimates of latitude and longitude can be derived by calculating solar noon, midnight, or both from archived light thresholds (i.e. sunrise and sunset) compared against an internal clock (Hill and Braun 2001, Ekstrom 2004, Stutchbury et al. 2009). Although geolocators require recapturing marked individuals and do not produce location estimates with the precision of satellite or GPS transmitters, they are one of the few methods currently available to answer questions about migratory connectivity and wintering locations of small songbirds. Despite increasingly widespread deployment on songbirds larger than ~20 g, geolocators have only recently reached a size appropriate for small songbirds, with deployment and recovery reported for three species <20 g, but no species <12 g (Bridge et al. 2013). As with many novel technologies, the impact of geolocators on marked individuals and potential biases in the resulting data have not yet been well addressed, especially for the smallest species.

Bridge et al. (2013) suggested that the light sensor of a geolocator must be elevated above the body of the bird (usually achieved with stalks >5 mm) to avoid potential shading of the sensor by feathers. To our knowledge, however, variation among location estimates derived from stalked versus stalkless geolocator units has not been evaluated. Bowlin et al. (2010) estimated the aerodynamic cost of stalkless geolocators on birds and found that increased drag reduced the flight capabilities of birds more than the effects of attaching additional mass. Bowlin et al. (2010) estimated a potential decrease in flight range (i.e. the distance an individual can fly given a known amount of fuel) of 14% for a 10-g species marked with a 0.5-g stalkless geolocator (5% of mean body mass). Flight range, especially of small songbirds, would likely be reduced even further with the addition of a stalk to a geolocator unit.

Some information has been synthesized on the effects of geolocators on birds, with conflicting results depending on taxa and attachment methods. In a meta-analysis of geolocator deployment on songbirds, Bridge et al. (2013) concluded geolocators have minimal effects on return rates. A separate meta-analysis reported an overall negative impact of geolocators on birds (Costantini and Møller 2013). However, the Constantini and Møller (2013) dataset included band-mounted geolocators on seabirds and raptors, which they determined had a larger impact than harness-mounted geolocators on songbirds. Geolocators have been reported to reduce productivity or body mass in Tree Swallows (*Tachycineta bicolor*; Gómez et al. 2014), Barn Swallows (*Hirundo rustica*; Scandolara et al. 2014), and Northern Wheatears (*Oenanthe oenanthe*; Arlt et al. 2013). Negative impacts of other markers on songbirds often go unpublished (Hill and Elphick 2011), suggesting the negative geolocator effects reported so far do not represent a comprehensive assessment.

We conducted a controlled assessment of the ability of Golden-winged Warblers (*Vermivora chrysoptera*) to carry geolocators to and from their wintering grounds. At ~9 g, Golden-winged Warblers are the smallest species to date to be used in a geolocator study (Bridge et al. 2013, McKinnon et al. 2013). We tested the effects of geolocators on return rates, territory fidelity, and body mass by comparing birds with geolocators to a color-banded control group at 2 study areas. To assess the necessity of a light stalk, we compared differences in mean spring arrival date and precision of location estimates between stalked and stalkless geolocators.

METHODS

In May 2013, we geolocator-marked Golden-winged Warblers in the North Cumberland Wildlife Management Area in Campbell County, Tennessee, USA (36.2°N, 84.2°W) and Rice Lake National Wildlife Refuge (NWR) in Aitkin County, Minnesota, USA (46.5°N, 93.3°W). We captured breeding male Golden-winged Warblers in mist nets using call playback of conspecific vocalizations. When possible, we avoided targeting individuals after 0900 hr to reduce the likelihood that we would capture an individual outside of its territory (Streby et al. 2012). We banded all birds with standard U.S. Geological Survey aluminum legbands and 1–3 plastic color legbands. We recorded body mass using a digital scale to the nearest 0.01 g and recorded all capture locations using handheld GPS units (GPSMAP 76 or eTrex Venture HC Global Positioning System; Garmin, Schaffhausen, Switzerland), averaging locations using 100 points to achieve <5 m accuracy. At each site, we attached 20 geolocators (10 with a 5-mm light stalk and 10 stalkless; model ML6240; Biotrack, Wareham, UK) using the tracking-device attachment technique described in Streby et al. (2015), a modification of the Rappole and Tipton (1991) leg-loop harness design. Geolocators with harnesses weighed 0.51 g (stalked; 5.7% of mean body mass; 5.0–6.2% of individual body mass) or 0.45 g (stalkless; 5.0% of mean body mass; 4.7–5.6% of individual body mass). We considered all other color-banded, male Golden-winged Warblers at our sites to be control birds ($n = 12$ in Tennessee and $n = 20$ in Minnesota).

In May 2014, we initiated searches for both control and geolocator-marked individuals within 500 m of their 2013 capture location. Because no individual was resighted >150 m from its 2013 capture point, we ceased systematic searching efforts after 500 m due to logistical constraints. We used the same methods as during initial capture to recapture and record body mass and capture location for both geolocator-marked and control individuals. We confirmed the identities of any individuals that we did not recapture using their unique color-band combination and, for geolocator-marked birds, visually confirming the presence of a geolocator.

Statistical Analyses

We used ArcGIS 10.0 Geographic Information System (GIS) software (Environmental Systems Research Institute, Redlands, California, USA) to measure the distances between capture locations from 2013 and recapture locations from 2014. Because we did not record the mass or location of the majority of control birds in Tennessee, we used a Student's t-test to compare the annual change in capture location and annual change in mass between geolocator-marked and control birds using only individuals captured in Minnesota. We compared return rates between all geolocator-marked and control birds using a chi-square test of independence. We used logistic regression to assess the impact of the explanatory variable of mass at time of geolocator attachment on return rates with a generalized linear model in R (ver. 2.14.1, R Foundation for Statistical Computing, Vienna, Austria). We used a Z-test to determine if regression coefficients were significantly different from zero.

We compared return rates between Golden-winged Warblers equipped with stalked versus stalkless geolocators using a chi-square test of independence. We compared the annual change in mass and annual change in capture location between birds marked with stalked geolocators and those marked with stalkless geolocators using Student's t-tests. We used BASTrak (Biotrack, Wareham, UK) to download and analyze data from geolocators using the methods described in Delmore et al. (2012). We assessed the precision of breeding location estimates (i.e. the distance between geographic mean location and all daily locations estimated from unedited geolocator data) with ArcGIS 10.0 GIS software using

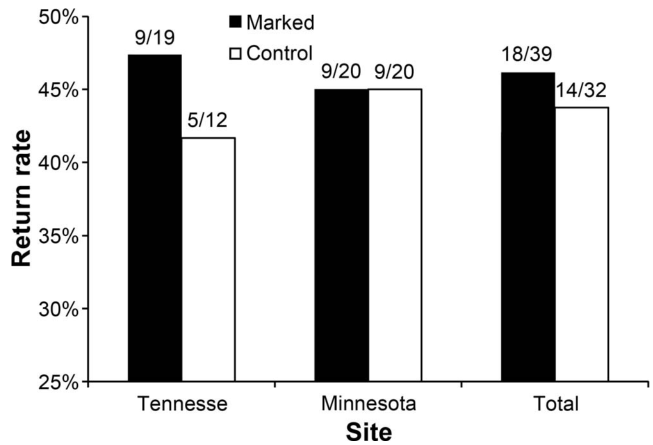

FIGURE 1. 2014 return rates of male Golden-winged Warblers marked with geolocators compared with color-banded–only control individuals in the Cumberland Mountains, Tennessee, and Rice Lake National Wildlife Refuge, Minnesota.

unedited noon location estimates from 45 days of the 2013 breeding season (May 16–June 29 in Tennessee and June 1–July 15 in Minnesota) when birds were most likely to remain near capture locations. We compared the mean variation (i.e. the average distance from each estimated location to the mean estimated location) between stalked and stalkless geolocators using a Student's t-test. We used geolocator-based daily location estimates to identify the mean spring arrival date in 2014 for each recaptured geolocator-marked Golden-winged Warbler. We considered all statistical tests to be significant at an α level of 0.05.

RESULTS

In 2014, we detected 19 Golden-winged Warblers that we had geolocator-marked the previous year ($n = 40$). One of those birds in Tennessee returned without a geolocator or harness, and we censored that bird from analysis because it was not possible to know when the geolocator detached. In total, we resighted 47% (9 of 19) of geolocator-marked birds that returned in Tennessee and 45% (9 of 20) of geolocator-marked birds that returned in Minnesota (Figure 1). We recaptured 6 of those 9 geolocator-marked birds in Tennessee. Of the 3 geolocators we did not recover, we were unsuccessful in capturing 2 individuals despite $\geq$5 extensive recapture attempts on separate days throughout the nesting season. We observed one additional individual with its geolocator on 2 occasions in late April but were unable to locate that individual once recapture efforts began in early May. We recaptured all 9 geolocator-marked birds that we resighted in Minnesota. All 15 recaptured geolocators successfully collected daily light data and 13 geolocators (87%) exceeded the expected

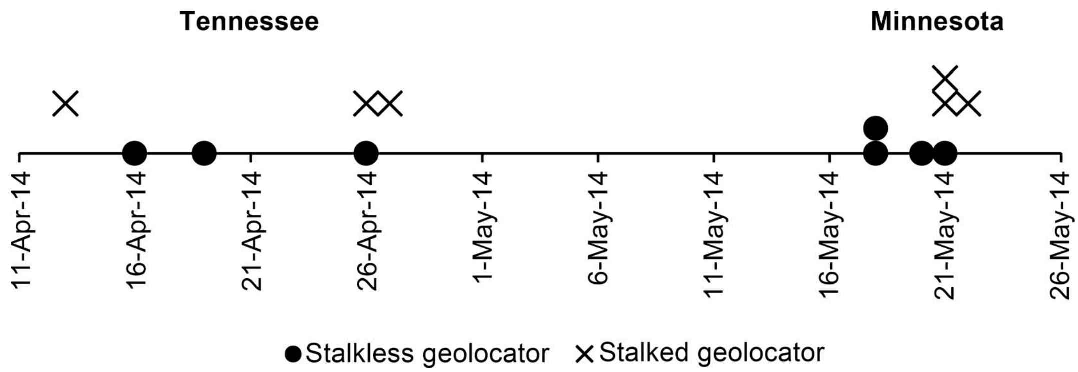

FIGURE 2. 2014 arrival dates of male Golden-winged Warblers carrying stalked and stalkless geolocators in the Cumberland Mountains, Tennessee, and Rice Lake National Wildlife Refuge, Minnesota.

unit battery life and recorded arrival from spring migration. We observed 42% (5 of 12) of the control birds in Tennessee and 45% (9 of 20) of the control birds in Minnesota. Overall return rates did not differ between geolocator-marked and control birds (Figure 1; $\chi^2 = 1.97$, df = 1, $P = 0.84$). Change in body mass from 2013 to 2014 in Minnesota was similar between 9 geolocator-marked birds ($\bar{x} = +0.16$ g) and 8 control birds for which we recorded mass in both years ($\bar{x} = +0.43$ g; $t = -0.68$, $P = 0.25$). Mass at the time of geolocator attachment was not related to return rates ($Z = -0.98$, df = 35, $P = 0.33$) for 17 returning birds ($\bar{x} = 8.88$ g) and 20 birds that did not return ($\bar{x} = 9.02$ g). We observed no difference in inter-annual territory fidelity, with similar mean changes in capture location for 9 geolocator-marked birds ($\bar{x} = 66$ m) and 9 control birds ($\bar{x} = 62$ m; $t = 0.99$, $P = 0.83$) in Minnesota.

Fifty-six percent (5 of 9) of birds carrying stalked geolocators and 40% (4 of 10) carrying stalkless geolocators returned in Tennessee. Thirty percent (3 of 10) of birds carrying stalked geolocators and 60% (6 of 10) carrying stalkless geolocators returned in Minnesota. Return rates did not differ between stalked (42%) and stalkless geolocators (50%; $\chi^2 = 0.77$, df = 1, $P = 0.62$). The change in mean mass also did not differ between 3 birds with stalked geolocators ($\bar{x} = +0.05$ g) and 6 birds with stalkless geolocators ($\bar{x} = +0.21$ g; $t = 0.36$, $P = 0.64$) in Minnesota. Similarly, the distance between the capture location and recapture location did not differ for 3 birds with stalked geolocators ($\bar{x} = 33$ m) and 6 birds with stalkless geolocators ($\bar{x} = 83$ m; $t = -1.29$, $P = 0.12$) in Minnesota. Mean distance of unedited daily location estimates from geographic mean estimate of 2013 breeding locations was 167 km for Golden-winged Warblers equipped with stalkless geolocators ($n = 7$) and 162 km for those equipped with stalked geolocators ($n = 6$; $t = 0.37$, $P = 0.64$). Mean spring arrival dates were similar between birds carrying stalked (Tennessee = April 22, Minnesota = May 21; Figure 2) and stalkless geolocators (Tennessee = April 20, Minnesota = May 20; Figure 2).

DISCUSSION

Ours is the first study we are aware of to investigate the effects of geolocators on songbirds weighing <12 g and the first to assess differences between stalked and stalkless geolocators. Due to the relatively small sample sizes in our study, the statistical power of our evaluations is limited. However, our results suggest that songbirds weighing as little as 9 g can successfully carry geolocators, and we observed no measurable impacts on return rates, body mass, or migration chronology, which are the parameters most likely to be negatively affected in small birds carrying markers. With the mass of geolocators and other markers decreasing nearly annually, the number of studies on small songbirds using these markers is likely to increase. Our results suggest that at least for some small songbirds, geolocator attachment is a viable method of obtaining unbiased information about migration and wintering areas.

As with any new marker or marking technique, it is important that the potential impacts of marking be evaluated. We did not observe any negative impacts on the parameters most likely to affect geolocator-marked Golden-winged Warblers in our study, but note that we did not assess potential impacts on other important parameters (e.g., reproductive success during and after carrying units). However, the impact of markers on Golden-winged Warblers is likely variable. A prior study showed no effects of radio-transmitters on productivity or survival of adult female Golden-winged Warblers on breeding sites (Streby et al. 2013). However, Chandler (2011) reported reduced return rates of wintering male Golden-winged Warblers when individuals carried radio transmitters into migration, suggesting that both the type of marker and the period when the marker is deployed may influence whether there are negative effects.

The stalkless geolocators we deployed were 0.06 g (12%) lighter and had a lower profile than stalked geolocators. Although we did not quantify the aerodynamics of either type of geolocator, stalkless geolocators were likely more aerodynamic than stalked geolocators; a factor that may be more important than mass for migrating songbirds (Bowlin et al. 2010). We observed no evidence that stalks negatively affected Golden-winged Warblers, suggesting they were capable of carrying the larger, less streamlined units. However, we found no evidence that light stalks increased the precision of location estimates for geolocators attached using a figure-eight backpack harness, and suggest that the likelihood of feather shading can be negligible using the attachment method described by Streby et al. (2015). Although neither geolocator configuration failed in our study, using stalkless units may also reduce the likelihood of unit failure due to stalk detachment (e.g., Rodríguez et al. 2009, Delmore et al. 2012, Renfrew et al. 2013). Furthermore, at least one study found that reducing the length of light stalks increased return rates in geolocator-marked individuals (B. Stutchbury, unpublished data reported in Bridge et al. 2013). Although we did not detect a difference in precision of location estimates derived from stalked versus stalkless geolocators, we suggest that this result needs to be experimentally tested for larger songbirds that have longer, denser feathers. We also suggest that further evaluations of the potential impacts of geolocators on small songbirds are necessary, and reporting of both negative and positive results in the published literature will aid in fully assessing application of this technology.

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Ethics statement: We captured, marked, and collected data from birds following Protocol No. 561, approved by the University of Tennessee Institutional Animal Care and Use Committee and Protocol No. 1004A80575, approved by the University of Minnesota Institutional Animal Care and Use Committee.

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