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Source: The Condor, 117(2) : 249-255

Published By: American Ornithological Society

URL: <https://doi.org/10.1650/CONDOR-14-182.1>

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RESEARCH ARTICLE

Minimizing marker mass and handling time when attaching radio-transmitters and geolocators to small songbirds

Henry M. Streby,^{1*} Tara L. McAllister,² Sean M. Peterson,² Gunnar R. Kramer,² Justin A. Lehman,^{2,a} and David E. Andersen³

¹ Department of Environmental Science Policy and Management, University of California, Berkeley, California, USA

² Minnesota Cooperative Fish and Wildlife Research Unit, Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, St. Paul, Minnesota, USA

³ U.S. Geological Survey, Minnesota Cooperative Fish and Wildlife Research Unit, St. Paul, Minnesota, USA

^a Current address: Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville, Tennessee, USA

* Corresponding author: henrystreby@gmail.com

Submitted November 15, 2014; Accepted February 15, 2015; Published April 29, 2015

ABSTRACT

Radio-transmitters and light-level geolocators are currently small enough for use on songbirds weighing <15 g. Various methods are used to attach these markers to larger songbirds, but with small birds it becomes especially important to minimize marker mass and bird handling time. Here, we offer modifications to harness materials and marker preparation for transmitters and geolocators, and we describe deployment methods that can be safely completed in 20–60 s per bird. We describe a 0.5-mm elastic sewing thread harness for radio-transmitters that allows nestlings, fledglings, and adults to be marked with the same harness size and reliably falls off to avoid poststudy effects. We also describe a 0.5-mm jewelry cord harness for geolocators that provides a firm fit for >1 yr. Neither harness type requires plastic or metal tubes, rings, or other attachment fixtures on the marker, nor do they require crimping beads, epoxy, scissors, or tying knots while handling birds. Both harnesses add 0.03 g to the mass of markers for small wood-warblers (Parulidae). This minimal additional mass is offset by trimming transmitter antennas or geolocator connection nodes, resulting in no net mass gain for transmitters and 0.02 g added for geolocators compared with conventional harness methods that add >0.40 g. We and others have used this transmitter attachment method with several small songbird species, with no effects on adult and fledgling behavior and survival. We have used this geolocator attachment method on 9-g wood-warblers with no effects on return rates, return dates, territory fidelity, and body mass. We hope that these improvements to the design and deployment of the leg-loop harness method will enable the safe and successful use of these markers, and eventually GPS and other tags, on similarly small songbirds.

Keywords: attachment methods, geolocation, migration, telemetry, warbler, wildlife tracking

Minimizando el peso de los marcadores y el tiempo de manipulación al colocar radio transmisores y geolocalizadores a aves canoras pequeñas

RESUMEN

Los radio transmisores y los geo-localizadores con detectores de nivel de luz son actualmente lo suficientemente pequeños como para ser usados en aves canoras <15 g. Se usan varios métodos para fijar estos marcadores a aves más grandes, pero con aves canoras pequeñas es particularmente importante minimizar el peso de los marcadores y el tiempo de manipulación. En este trabajo, proponemos una serie de modificaciones a los materiales del arnés y a la preparación de los marcadores para los transmisores y los geo-localizadores, y describimos métodos de fijación que pueden implementarse de modo seguro en 20 a 60 segundos por ave. Describimos un arnés de hilo de coser elástico de 0.5 mm para radio transmisores que permite marcar pichones, volantones y adultos con el mismo tamaño de arnés, y que se desprende de modo fiable para evitar efectos posteriores al estudio. Adicionalmente, describimos un arnés de cordón de joyería de 0.5 mm para los geo-localizadores que brinda un ajuste firme por >1 año. Ninguno de los tipos de arnés requiere tubos de plástico o metal, anillos u otros accesorios de fijación en el marcador, ni tampoco requieren engarzado de cuentas, pegamentos, tijeras o ataduras mientras se manipula a las aves durante la colocación. Ambos arneses agregan 0.03 g de peso a los marcadores para las pequeñas aves Parulidae. Este aumento mínimo del peso es compensado por el recorte de las antenas de los transmisores o de los nodos de conexión de los geo-localizadores, lo que conlleva a un aumento nulo del peso de los transmisores y a un aumento de 0.02-g para los geo-localizadores, en comparación con los arneses convencionales que agregan >0.40 g. Nosotros y otras personas han usado este método de fijación con muchas especies de aves canoras pequeñas, sin efectos en el comportamiento ni en la supervivencia de los adultos y de los pichones. Hemos usado este método de fijación del geo-localizador en Parúlidos de bosque de 9 g sin efectos en las tasas de retorno, las fechas de retorno, la

fidelidad territorial y el peso corporal. Esperamos que estas mejoras al diseño y al método de colocación del arnés de las perneras permitan un uso seguro y exitoso de estos marcadores, y eventualmente de GPS u otras marcas en aves pequeñas del mismo tipo.

Palabras clave: geo-localización, métodos de fijación, migración, Parulidae, rastreo de vida silvestre, telemetría

INTRODUCTION

The knowledge that can be gained from marking songbirds with radio-transmitters (hereafter, transmitters) and data loggers such as light-level geolocators (hereafter, geolocators) is immense (e.g., Anders et al. 1998, Stutchbury et al. 2009, Delmore et al. 2012, Streby et al. 2014). Miniaturization of these markers has progressed to allow birds <15 g to be marked (Streby et al. 2012, Salewski et al. 2013, Zenal et al. 2014). A basic assumption of studies involving marking animals is that the application of markers and the carrying of those markers by individuals do not affect their behavior or survival (White and Garrott 1990). Therefore, when marking very small animals, key objectives are to minimize the mass of the marker and the time spent handling an animal when applying the marker. The leg-loop figure-eight harness design described by Rappole and Tipton (1991) is used in most radio-telemetry and light-level geolocation studies of songbirds (Bridge et al. 2013, Cox et al. 2014). However, there is substantial variation in the interpretation and application of that design, although authors generally report the method as the leg-loop or figure-eight harness design, and cite Rappole and Tipton (1991).

Although the details of author-specific harness designs and attachment methods are rarely described in the peer-reviewed literature, many are readily accessible online, and these methods usually involve considerably more and heavier materials and far greater handling time than described by Rappole and Tipton (1991). For example, harness materials ranging from embroidery thread to Teflon ribbon are attached to markers prefabricated with metal and plastic tubes and rings intended to facilitate the attachment of harnesses to transmitters and geolocators. In addition, although Rappole and Tipton (1991) described a fully prepared harness applied with minimal handling time in the field, incomplete harnesses are often fitted to birds using scissors, crimping beads, the tying of knots, and application of epoxy, requiring extensive handling time. Some heavy and strong materials, paired with complicated attachment procedures, may be necessary for marking larger birds that might destroy lighter harnesses, or for species with great individual size variation. However, those materials and methods are not necessary for marking small songbirds, and their presumed necessity likely contributes to the opinion that very small species, such as many wood-warblers (Parulidae), cannot be safely marked with transmitters or similar markers (Confer et al. 2011).

Caution in marking very small songbirds is justified, considering the apparent underreporting of negative transmitter effects on songbirds (Hill and Elphick 2011), the relatively low return rates, compared with controls, of 12-g birds marked with geolocators (Salewski et al. 2013), and the paucity of controlled comparisons in transmitter and geocator studies in general (but see Townsend et al. 2012, Bridge et al. 2013). However, instead of waiting for transmitters and geolocators to become small enough to accommodate the mass of conventional harness designs, here we demonstrate that considerable progress can be made in minimizing the mass of the harness itself (Table 1). We suggest a return to the simplicity of Rappole and Tipton's (1991) original design, and we offer modifications to minimize harness mass and deployment time. We developed and tested this method with controlled comparisons for both transmitters and geolocators, with no measurable effects on birds as small as 9 g.

METHODS

Radio-Transmitters

We used the leg-loop harness design (Rappole and Tipton 1991), with the modifications described below, to deploy radio-transmitters on >500 adult, nestling, and fledgling Ovenbirds (*Seiurus aurocapilla*; 13 g at fledging, 19 g as adults) and Golden-winged Warblers (*Vermivora chrysoptera*; 7 g at fledging, 9 g as adults), with no effects, compared with banded control birds, on behavior, reproductive success, and survival (Streby and Andersen 2013, Streby et al. 2013). We have instructed others in this method who have used it to mark Japanese White-eyes (*Zosterops japonicus*; 10 g; Wu et al. 2014), Acadian Flycatchers (*Empidonax virescens*; 13g; J. Jenkins personal communication), and Golden-winged Warblers (J. Lehman and D. McNeil personal communication), with no apparent effects on behavior or survival (i.e. no observations of obvious behavioral changes or limitations, or of obvious transmitter-caused mortality). Additionally, we and others have used this method to radio-tag larger songbirds, including Bachman's Sparrows (*Peucaea aestivalis*; 21 g; A. Fish personal communication), Hermit Thrushes (*Catharus guttatus*; 30 g), Wood Thrushes (*Hylocichla mustelina*; 50 g), and Omao (or 'Ōma'o; *Myadestes obscurus*; 50 g; Wu et al. 2014), with no indication that heavier harness materials or more complicated deployment methods are necessary to avoid harness failure in these species.

TABLE 1. Masses (g) of materials used to deploy a geolocator on a small songbird using a common conventional method and our modifications.

Method	Manufactured parts				Added parts		Total, deployed unit	Mass limit of bird ^c
	Base geolocator ^a	Anterior tube	Posterior rings & nodes ^b	Light stalk	Crimping beads	Harness		
Conventional	0.43	0.10	0.10	≥0.05	≥0.06	≥0.12	≥0.89	≥17.8
Modified	0.43	0.00	-0.01	0.00	0.00	0.03	0.45	9.0

^a Biotrack model ML6340 (Biotrack, Wareham, Dorset, UK), guaranteed for 9 mo, but 87% collected data for >12 mo in our study.

^b Metal rings that normally double as points of electrical connection and harness connection are unnecessary with our modified method, and we trim 0.01 g off the simple electrical nodes.

^c Minimum mass of birds that can be marked, assuming that the marker is ≤5% of body mass.

Our modifications to Rappole and Tipton's (1991) transmitter harness design include harness material, construction, and attachment to the transmitter. Rappole and Tipton (1991) described using catheter tubing or other ligature materials ≥1 mm in diameter to avoid skin abrasion. We used a very thin (~0.5 mm) black elastic sewing thread (Gutermann Thread, Gutach-Breisgau, Germany; available online and at most craft stores) and observed no skin irritation around the legs of birds that wore the harness >50 days. We speculate that this lack of abrasion is due to each loop of this harness being a true loop that fits snugly around the thigh against the body and does not slide forward and backward as harnesses attached to the front and back of a marker may do. Thin elastic sewing thread offers multiple benefits in addition to having considerably less mass than thicker, more rigid materials. First, the elasticity allows for ease of attachment when stretching around a bird's leg. Second, the elasticity allows for a one-size-fits-all approach within species lacking substantial individual size variation, and harnesses sized for adults fit securely on nestlings and fledglings as they grow. Finally, thin elastic thread degrades and allows the harness to fall off the bird 40–70 days after deployment. This is important because small songbirds that migrate with radio-transmitters attached with thicker, longer-lasting harness materials can experience reduced return rates (Chandler 2010). A weak link of rubber band or other soft material can be used if shorter monitoring periods are necessary for retrieving unexpired transmitters or when data are collected for brief periods. However, fledgling Ovenbirds, for which our transmitters lasted >50 days, started shedding harnesses with no weak link after 40 days. In addition, adult female Golden-winged Warblers that we marked before the nesting season lost their harnesses during the postfledging period, when we observed them feeding radio-tagged fledglings 50–70 days after female marking.

Preparation of the figure-eight harness is as simple as tying your shoes (Figure 1). We recommend determining appropriate harness size with field trials on a small sample

of your focal species if the species has not been marked before. Formulas for estimating harness size based on body mass have been published with the intent of reducing this time and effort in the field (e.g., Naef-Daenzer 2007). However, although such formulas might produce a valuable starting point for field trials, the Naef-Daenzer (2007) formula overestimated harness size and produced harnesses that fell off Golden-winged Warblers (75% fell off), Ovenbirds (100%), and Hermit Thrushes (100%) within 24 hr of deployment during our initial trials (H. Streby personal observation).

Attachment of the harness to the transmitter requires only two tiny beads of superglue (Figure 1; we use Loctite Gel Control; Henkel Corporation, Rocky Hill, Connecticut, USA). This method minimizes the mass of the transmitter unit by removing the need for prefabricated plastic or metal rings or tubes for attaching or tying the harness to the transmitter. We have never had a transmitter ($n > 500$) come loose from the harness with this method. If transmitter antennas are trimmed to 6–7 cm (recommended to avoid tangling in vegetation), the 0.03-g mass of this harness can be entirely offset. This method also minimizes handling time of individuals or broods by having transmitters prepared for deployment before capturing birds or removing broods from nests. We prepared harnesses and attached them to transmitters >12 hr before deployment. Methods that involve fitting, tying, crimping, cutting, and gluing harnesses during bird handling often require >5 min per bird of unnecessary handling time and increased risk of injury from scissors and crimping pliers. Our method is also faster than glue-on methods that require drying time, which varies by glue type and environmental conditions. Using our method, a transmitter can be safely attached to a small songbird by an experienced handler in ~20 s.

We attach the transmitter to the bird in the same fashion as Rappole and Tipton (1991), but we offer minor clarifications here. Rappole and Tipton (1991) describe pulling the harness loops up to the proximal ends of the thighs, but their figure 1 does not include the thigh and

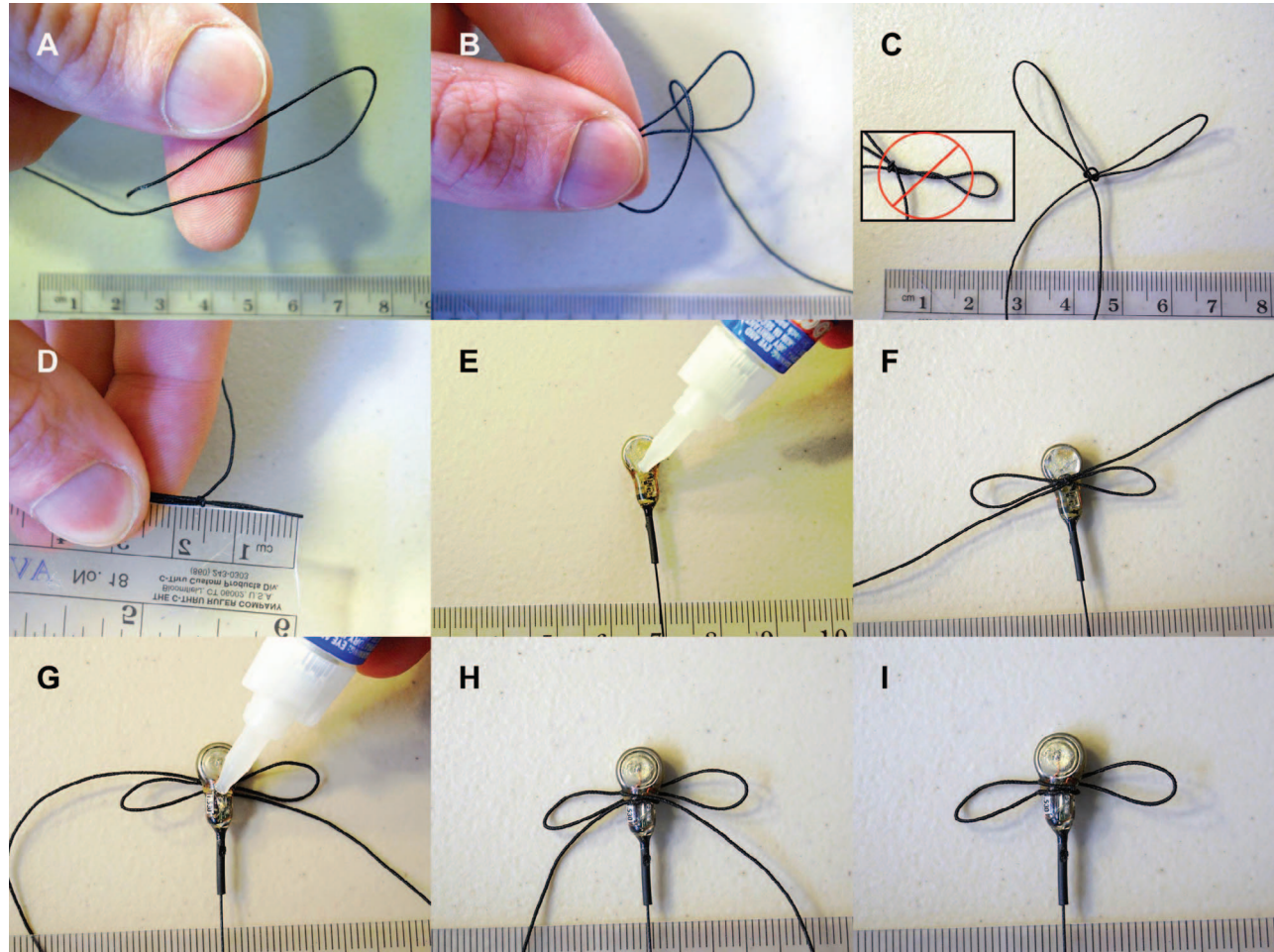


FIGURE 1. Building a harness and applying it to a radio-transmitter. The 0.5-mm elastic sewing thread is first cut into a segment of ≥ 10 cm. Then (A) one end of the thread is made into one loop, (B) the remaining long end is wrapped around the first loop, and (C) the long end is pulled through, resulting in a second loop and resembling bunny ears, with no twisting in the loops (C, inset). The knot is then tightened and, (D) using a thin ruler, the loops are adjusted to the desired inner-loop length when pulled taut but not stretched. The harness is attached to the transmitter by (E) placing a small bead of glue on the bottom of the unit at the base of the battery, roughly at the balancing point of the transmitter. Next, (F) the knot of the harness is held on the bead of glue with the harness loops held perpendicular to the transmitter while the glue dries (a few seconds). Then (G) the transmitter is rolled over and another bead of glue is applied in the same position on the top of the unit. Finally, (H) the long tails of the harness are pulled snugly around the transmitter and held in that second bead of glue until it dries, and (I) the long tails are clipped flush with the transmitter. For geolocators the method is identical, except that the sewing elastic is replaced by 0.5-mm Stretch Magic jewelry cord (Pepperell Braiding Company, Pepperell, Massachusetts, USA), and a bead of glue may be required to hold the knot made in step C due to the less agreeable material. For large numbers of markers, an assembly line approach is recommended for efficiency. A detailed presentation of this harness-making method and a video of geolocator deployment are available on the Minnesota Cooperative Fish and Wildlife Research Unit website (<http://mncoopunit.cfans.umn.edu/published-methods-and-data/methods/>) or by contacting the corresponding author.

depicts a loose-fitting harness loop riding somewhere distal to the knee. In our method, the loop should fit snugly against the body at the proximal end of the thigh. This fitting should be double-checked before release; if the harness loop is loose or distal to the knee the transmitter will fall off shortly after deployment (H. Streby personal observation). Rappole and Tipton (1991) also describe the transmitter sitting on the back of the bird with 1–2 mm of play. An additional benefit

of the elastic harness is that it fits snugly against the bird, reducing the probability of skin abrasion from marker movement and reducing the chance of vegetation tangling under the harness. The transmitter can be fitted below the feathers for concealment or atop the feathers for less feather displacement, but either way it should fit snugly enough to not move, but should not be so snug that it affects behavior (i.e. the ability to perch correctly).

Geolocators

Our geolocator harness design is identical to the design that we use for transmitters, but is constructed of a different harness material. For geolocator harnesses we use 0.5-mm black Stretch Magic jewelry cord (Pepperell Braiding Company, Pepperell, Massachusetts, USA). Again, Rappole and Tipton (1991) called for materials ≥ 1 mm in diameter, and thicker versions of this jewelry cord have been used in geolocator studies (e.g., Ross et al. 2014). However, doubling the diameter of a round material quadruples its mass, so 1-mm cord would add 0.09 g of unnecessary mass (a 20% increase in total marker mass) to our Golden-winged Warbler marker. Although the jewelry cord and elastic thread that we use are similar in diameter, the jewelry cord has $\sim 10\%$ of the elasticity of the sewing thread and shows no sign of degradation 1 yr after deployment on birds (Peterson et al. 2015). As with transmitters, we attach the harness to the geolocator >12 hr before deployment with two tiny beads of superglue and with no prefabricated tubes, rings, or other attachment points on the geolocator. We have not had a geolocator ($n = 40$) come loose from the harness with this method. For Golden-winged Warblers, the attached harness adds 0.03 g to the geolocator. We partially offset that mass by clipping ~ 1 mm from each of the nodes used to connect the geolocator to a computer (this does not affect the ability to download data).

To attach a geolocator to a small songbird we again follow Rappole and Tipton's (1991) attachment methods, with further modifications due to the limited elasticity of the harness material. The two key modifications include an additional step to work the less-flexible material into place and a convenient method for ensuring that the geolocator rests atop the feathers to reduce potential feather obstruction of the light sensor. We first slide the right harness loop over the right foot to the tibiotarsal joint (as opposed to pulling the loop above the knee as with a transmitter harness). We then place a long, thin strip of paper or plastic on the bird's back, from the neck to the tail, covering the synsacrum where the geolocator will rest. After placing this strip, we pull the geolocator across the bird's back and slide the left harness loop over the outside of the closed left tibiotarsal joint. This method exploits the natural flexibility of passerine legs, so to perform it correctly we do not secure the right leg while we pull the left loop over the left tibiotarsal joint, but instead allow the right leg to move naturally behind the bird. This flexibility is similar to moving your elbows behind your back. We then pull the left harness loop up the left foot and over the toes, resulting in the geolocator resting on top of the strip with both loops inside the tibiotarsal joints. From this point we work both loops above the knees to rest snugly against the body, just as with the transmitter harness. Extending the human elbow analogy, this harness

attachment method is similar to putting backpack straps on one elbow at a time behind your back, and then shrugging the pack into place on your shoulders. After securing the geolocator harness on both legs, we pull the strip out from under the harness toward the tail, thereby smoothing all feathers underneath the harness. If some feathers are left out of place, we pull the paper through again in the same direction to flatten those feathers under the geolocator and harness. Using this method, we have found that light stalks are not necessary to keep geolocator sensors above the feathers of small songbirds (Peterson et al. 2015). Interestingly, Golden-winged Warblers returning with geolocators tended not to have feathers over the geolocator, despite a year of molting and preening (H. Streby personal observation).

Similarly to the transmitter attachment method, this geolocator attachment method requires substantially less handling time than fitting incomplete harnesses in the field. Using our method, an experienced handler can independently attach a geolocator to a small songbird in <1 min. We used this method on adult male Golden-winged Warblers in 2013–2014 and observed a 46% return rate for geo-tagged birds, compared with 44% for control birds (Peterson et al. 2015). Only 1 of 40 marked Golden-winged Warblers returned without its geolocator or harness; this bird was one of the first that we marked when still working out the harness loop size (Peterson et al. 2015). Unlike our results with transmitters, we observed a small area ($\sim 3 \times 3$ mm) of callused skin under the geolocator on many Golden-winged Warblers. This featherless area was not directly associated with the harness and was more common on birds carrying geolocators with light stalks, which might have been due to the greater mass of those units or might have indicated that those units moved around more, presumably from wind drag and bumping the stalk on vegetation. However, because stalks are not necessary to keep light sensors above the feathers of Golden-winged Warblers (Peterson et al. 2015), and likely other small songbirds, we do not anticipate this abrasion being a problem in future studies using this method.

RESULTS

Our method for minimizing the mass of markers and the handling time required to deploy them on small songbirds has proven successful with the species marked so far. However, we caution that pilot studies with marked and control groups of moderate numbers of individuals remain important for new studies because marker effects on birds tend to be species- and study-specific (Sykes et al. 1990, Hill et al. 1999, Dougill et al. 2000, Mattsson et al. 2006, Hill and Elphick 2011). In addition, we caution that adult songbirds can take several minutes to acclimate to a new

marker and should therefore be released in a reasonable location (i.e. not into wet vegetation or near a flock of corvids) and should be monitored closely until regular behavior is resumed. This acclimation period, which can entail short, awkward flights and sometimes pecking at new markers with the bill, has been more pronounced in males than in females in our experience, possibly due to females being more accustomed to sudden changes in mass distribution (i.e. laying eggs). We have observed no differences in behavior between radio-tagged nestlings and their unmarked broodmates in the nest or after fledging, presumably due to acclimation occurring before fledging or flying.

DISCUSSION

As the development of progressively smaller and longer-lasting radio-transmitters, geolocators, and other data loggers continues, efforts to mark progressively smaller songbirds will follow. However, improvements to harness designs and attachment techniques can make current markers available for use on many species that are too small for marking with conventional methods. Compared with conventional harness designs, our modifications to the leg-loop harness mean that >80 additional Neotropical migrant songbirds, including 62% of wood-warblers, can be marked with geolocators, radio-transmitters, and other markers, with geolocators already available (assuming the arbitrary 5% body mass rule; mass data from Poole [2005]). We hope that improvements to these methods, as well as results showing the effects of markers, will become more common in the peer-reviewed literature. Finally, our method is intended to improve upon methods developed by Rappole and Tipton (1991), and we therefore recommend that any citation of this work be in addition to, and not in place of, citation of their work.

ACKNOWLEDGMENTS

We thank N. Seavy and R. Cormier for discussion on geocator harness design and materials. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government or other author affiliations.

Funding statement. These methods were developed during projects funded by the U.S. Fish and Wildlife Service and U.S. Geological Survey (USGS) through Research Work Order Nos. 73, 87, and 98 at the USGS Minnesota Cooperative Fish and Wildlife Research Unit; by the National Science Foundation through Postdoctoral Research Fellowship No. 1202729 to H.M.S.; and by the U.S. Department of Agriculture Natural Resources Conservation Service in a grant administered by Indiana University of Pennsylvania. None of the funding agencies influenced the content of this manuscript.

Ethics statement. We captured, marked, and collected data from songbirds following Protocol Nos. 0806A35761 and 1004A80575 approved by the University of Minnesota Institutional Animal Care and Use Committee (IACUC) and Protocol No. 561 approved by the University of Tennessee IACUC.

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