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Adjustable leg harness for attaching tags to small and medium-sized birds

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ABSTRACT. Rapidly expanding use of biologging devices is increasingly bringing novel insights into ornithology. Consequently, to maximize bird welfare and data quality, this growth calls for ensuring that devices are properly attached. Here, we provide a diagram for constructing a simple, field-adjustable leg-loop harness suitable for many small and medium-sized birds (< 200 g). We make harnesses prior to fieldwork using Teflon ribbon and a single crimp, then custom-fit each harness to birds in the field. This largely removes the need for pre-deployment field trials to determine harness size and ensures best possible fit. To evaluate the effects of harnesses on birds in the field, we marked 10 non-migratory species in central Amazonia and assessed their body mass at recapture with linear mixed models. Of 90 tags deployed, we recovered 43 (48%) an average of 359 days later. No individuals lost their tag. Additionally, when recaptures were compared to original captures, body mass was not lower for either tagged birds or 17 banded-only birds. This suggests that tags attached with our harness had little effect on birds, an encouraging result at a time when increasing options for tracking birds challenge researchers to properly attach various types of devices.

RESUMEN. **Arnés de pierna ajustable para colocar etiquetas a pájaros pequeños y medianos**
El creciente uso de registrador de datos automatizados aporta cada vez más conocimientos novedosos sobre la ornitología. En consecuencia, para maximizar el bienestar de las aves y la calidad de los datos, este crecimiento requiere garantizar que los dispositivos estén conectados correctamente. Aquí proporcionamos un diagrama para construir un arnés de perneras simple, ajustable en el campo, adecuado para muchas aves pequeñas y medianas (< 200 g). Hacemos arneses antes del trabajo de campo usando cinta de teflón y un solo rizado, luego ajustamos cada arnés a las aves en el campo. Esto elimina en gran medida la necesidad de pruebas de campo previas al despliegue para determinar el tamaño del arnés y garantiza el mejor ajuste posible. Para evaluar los efectos de los arneses en las aves en el campo, marcamos 10 especies no migratorias en la Amazonia central y evaluamos su masa corporal en la recaptura con modelos lineales mixtos. De 90 etiquetas implementadas, recuperamos 43 (48%) un promedio de 359 días después. Ningún individuo perdió su etiqueta. Además, cuando se compararon las recapturas con las capturas originales, la masa corporal no fue menor ni para las aves marcadas ni para las 17 aves anilladas. Las etiquetas adjuntas a nuestro arnés tuvieron poco efecto en las aves, un resultado alentador en un momento en el que el aumento de las opciones para rastrear aves desafía a los investigadores a conectar correctamente varios tipos de dispositivos.

Key words: Amazonia, Biological Dynamics of Forest Fragments Project, logger, tag effects, terrestrial insectivores, tracking

Biologging devices, along with the need for their proper attachment to birds, are becoming increasingly important in ornithological research. For small to medium-sized birds (< 200 g), radio-transmitters have been used for several decades, providing information primarily about short-distance movements and space use (Thompson 1994, Marzluff et al. 2004, Jirinec et al. 2016) and facilitating observations of cryptic or mobile species (Csada and Brigham 1994, Aubry and Raley 2002, Jirinec et al. 2011). Recent technological advances have spurred the "golden age of biologging," with the development of low-cost, miniature sensors (Wilmers et al. 2015). For birds, these include light-level geolocators, digitally coded radio-tags, archival global position system (GPS) loggers, and platform transmitter terminal (PTT) tags (see McKinnon and Love 2018 for a review). Several manufacturers such as Lotek and Cellular Tracking Technologies offer solar-powered tags that communicate

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with arrays of radio-receivers, cellphone towers, or satellites for long-term data collection without the need to recapture animals. Additionally, the recent launch of the International Cooperation for Animal Research Using Space (ICARUS) offers relatively inexpensive satellite tracking with solar-rechargeable tags weighing as little as 5 g. In addition to information about bird locations, many tags contain thermometers, accelerometers, gyroscopes, magnetometers, and proximity sensors, enabling often relatively long-term data collection that informs various biological fields.

Even in early radio-telemetry studies conducted over short time intervals (e.g., the breeding season), ornithologists were mindful of the possibility that attaching devices to birds comes with negative consequences for individuals and sought to mitigate these, both for the sake of the birds themselves and the quality of collected data. These approaches included minimizing tag mass (e.g., the "3–5% rule," but see Barron et al. 2010), handling time (Noel et al. 2013, Lamb et al. 2017), and using standardized attachment techniques (Kenward 2001). Given the diversity of devices available for birds and interest in tracking migratory species (i.e., long-term wear), deploying tags properly is becoming increasingly important.

Whether tags are detrimental to individual birds remains unresolved, but researchers agree that proper fitting is crucial. In a meta-analysis of 84 studies, Barron et al. (2010) found that devices had a negative impact on birds, particularly causing increased energy expenditure. Although harnesses and collars were associated with higher mortality, the authors suggested using adjustable harnesses because low retention rates of glue and tail mounts can limit their value. In contrast to Barron et al. (2010), a more recent meta-analysis of 122 studies that used phylogenetically controlled models found little effect of geolocators on small birds (Brlík et al. 2020). Although not statistically significant, this study revealed a weak negative influence on apparent survival that increased with device load and for geolocators attached with elastic harnesses. The latter finding was unexpected, and the authors suggested that the better performance of non-elastic harnesses may be because these are more commonly tailored to each individual, leading to a better (and often looser) fit.

The leg-loop harness designed by Rappole and Tipton (1991) is especially popular for attaching tags to small- and medium-sized birds, becoming a de facto standard for birds in these mass categories (Bridge et al. 2013). Hereafter, we only refer to the "Rappole and Tipton" (R-T) harness and set aside designs that could be better suited for certain species (e.g., Haramis and Kearns 2000, Chan et al. 2016). As with other harness types, the R-T harness requires properly sized loops that do not restrict bird movement, but are not too loose to cause tag loss or entangle birds in vegetation. To find a suitable size, researchers often rely on testing on captive birds (Chan et al. 2016), pre-deployment field trials, or predictive allometric functions (Naef-Daenzer 2007). Even then, variation among individuals often requires making several harnesses and choosing the best size for each captured bird in the field. This extra effort increases the logistical burden on researchers, handling time for birds and the possibility that the best fit is not achieved regardless.

Few guidelines exist for harness construction. For an overview of general considerations throughout the tagging process of mostly larger birds (and non-R-T harnesses), see Kenward (2001). Otherwise, researchers rarely publish detailed methods for attaching devices, but these often involve various materials (e.g., elastic jewelry cord, sewing thread, and Teflon) and tying of knots, gluing, or crimping (Streby et al. 2015). For birds < 10 g, Streby et al. (2015) described a variation of the R-T harness that minimizes mass and can be attached quickly, although this is a pre-made harness that comes with the fitting challenges described above. Even when ornithologists use elastic materials that make exact loop size less crucial, fitting concerns exist (Brlík et al. 2020). For larger birds that can destroy ultralight harnesses or carry heavier devices that require stronger materials, options for attachment are less restricted by mass and include adjustable harnesses that can be deployed quickly and individually fitted. Field ornithologists undoubtedly already use variations of the design we describe here, but detailed descriptions of these attachment methods are rarely published.

Here, we describe a simple, adjustable version of the R-T harness along with a field trial with 60 birds of 10 species monitored for ~ 1 yr. The harness is made using Teflon ribbon and a single crimp and works with common configurations of devices (such as an attachment tube in the front and tube or terminal loops in the back). Harnesses are made prior to field work and then simply cinched and crimped once on the bird. This field-adjustable design comes with several advantages over pre-made static configurations. No pilot studies are required to determine sizes, eliminating a time-consuming step that may be harmful to birds. Further, fit can be quickly individualized once a bird is captured to accommodate birds of different sizes. Thus, our specific objectives were to (1) describe harness construction and its fitting, and (2) determine the body mass of birds with and without harnesses to detect possible problems associated with wearing tags.

METHODS

Harness construction. Harnesses are constructed with Teflon ribbon and a single crimp. Tubular Teflon ribbon is suitable for long-term attachments because Teflon is biologically inert, environmentally stable, and the tube does not contain edges that may uncomfortably press against the skin (Kenward 2001). Although Teflon harnesses have been primarily used to attach tags to large birds (Mallory and Gilbert 2008, Humphrey and Avery 2014, Thaxter et al. 2014), narrow ribbons appropriate for much smaller devices are available. We used a 1.9-mm (flattened width) tubular ribbon made by Bally Ribbon Mills (Bally, Pennsylvania, USA) that weighed 0.0135 g cm^{-1}. Other manufacturers may also offer a suitable size. Ribbon of this width fits well to devices containing 1-2-mm attachment tubes or terminal loops (Fig. S1), while preventing excessive slipping through attachment openings that could impair fitting. For the crimp, we use a single-barrel, metal leader sleeve (size 4, American Fishing Wire, Coatesville, Pennsylvania, USA) made of an alloy that does not degrade in wet conditions. This crimp weighs 0.14 g ($N = 10$), measures 6.3 × 2.6 mm, and has a 1.8-mm (reported, but we measured 1.7 mm; $N = 5$) inner diameter into which fit two strands of ribbon with sufficient give to enable slipping. Unmodified, the crimp is needlessly long (and thus heavy), so we trim it to a quarter of its original length (1.5 mm = ~ 0.03 g) using diagonal pliers. Because trimming flattens the crimp, inserting a filling (we use an electrical wire; 1.5-mm thick) prior to cutting keeps the crimp sufficiently wide. The crimp can be further rounded with needle-nose pliers and filed to remove sharp edges. Although we report specifications for both the Teflon and crimp, researchers should note that manufacturers can change their products.

Weaving Teflon ribbon through the tag and crimp is achieved using synthetic sewing thread (Fig. 1, Video S1). For clarity, using two contrasting colors (e.g., black and white) is best. First, we cut a sufficiently long piece of Teflon to make harness loops large enough to fit over the bird's legs (oversized loops are not a problem—they will be reduced). All ties are made using two overhand knots. We refer to each end of the Teflon as end one (E1) and end two (E2). Now, we tie a piece of black sewing thread to Teflon E1, making sure the tip of E1 is tightly secured to the middle of the black thread, leading to two ~ 20 cm strands of thread attached to E1 (this provides extra security when pulling the Teflon). Looking at the tag dorsally, we pull the thread + E1 through the right anterior tube opening. For tags with posterior loop terminals, we continue by pulling the thread + E1 ventrally through the left posterior loop and repeat the process with Teflon E2 using a newly tied black thread (thread + E2 ventrally through the right posterior loop); both E1 + E2 should then stick upwards at the posterior end of the tag. For tags with a posterior tube rather than loops (Fig. 1), we push thread + E1 through the left posterior tube—pulling it sufficiently far that ~ 10 cm of Teflon is protruding from the right posterior tube opening. Both E1 and E2 should now stick out to the right of the tag. The trick now is to make E2 pass through the right posterior tube that is already occupied with one Teflon strand—this is the most challenging part of harness construction. First, we tie a new black thread to E2 in a similar fashion as we did with E1. We then use the white synthetic thread to tie both ends of the black thread to the first Teflon strand near the right posterior opening (this will help pass the black thread through the filled tube). Now, we gently pull on the first Teflon strand backwards out the left posterior tube until the white knot emerges. The black thread tied to E2 should now be visible and we cut away the white thread. At this time, we grip both the Teflon and the black thread near the left posterior opening and carefully continue pulling. This will move E2 into the right posterior opening (dissecting needle is helpful to push E2 in) and eventually out the left side (we then cut away the black thread). E1 should stick out the left posterior tube and E2 out the right posterior tube, making loops on either side of the tag whose sizes can be altered.

The crimp is used to complete the harness circuit. First, we adjust the loops to make sure they are large enough and equally sized and then fill both ends of the anterior tube with pliable glue (such as Pliobond; Ruscoe, Akron, Ohio, USA). Securing the front tube with flexible glue prevents the tag from slipping to the side of the bird's body (Vandenabeele et al. 2014) while avoiding harsh edges and facilitating reuse of devices, if applicable. Some researchers use simple knots instead of glue at this step—that can work too, although we prefer glue. After the front is secured, we push the two Teflon ends through the crimp—accomplishing this usually requires the use of threads or dissecting needles (e.g., one Teflon end first, then using threads to get the second end through as above). We suggest making the tag loops the same size and cutting the loose ends to equal length—this helps in fitting the harness to the bird because one can easily see that misaligned ends mean uneven loop sizes even when most of harness is covered with feathers. The harness is now ready to be fitted to a bird.

The final harness adjustment is made while on the bird in the field. We slip each loop over the bird's legs individually, then pull the tag up and away from the bird's back to ensure the harness loops are all the way up the upper leg (where it meets the belly). Tags with a front tube and hind loop terminals are easier to adjust—a single pull on the Teflon ends cinches the harness—and thus are possible to attach to birds by someone working alone. Fitting tags with two attachment tubes (Fig. 1) is

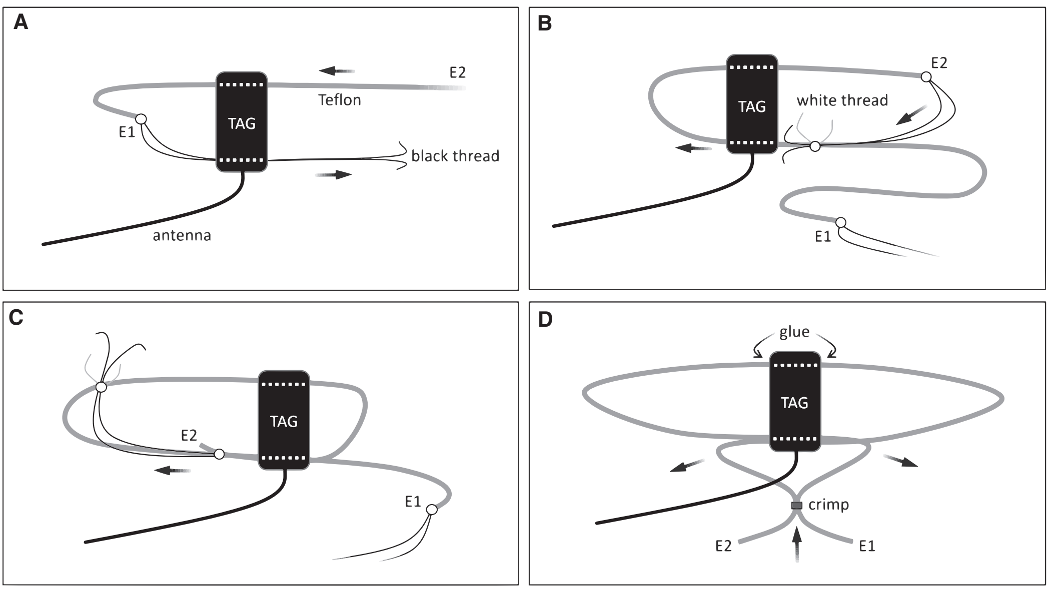

Fig. 1. Schematic for harness construction for tags with front and back attachment tubes. Arrows represent direction of motion. Panel (A): with tag viewed dorsally, a thin (black) synthetic sewing thread is tied (white circles represent knots) to the first Teflon ribbon end (E1) and pulled through the right anterior opening and then through the left posterior opening. Panel (B): another thread is tied firmly to the tip of the second Teflon end (E2) and the two strands are secured to E1 near the right posterior opening with an additional piece of (white) thread. Panel (C): E2 is pulled through the posterior attachment tube. Panel (D): with harness loops of equal size, glue is applied to the front attachment tube and a crimp is placed over Teflon ends.

easier with two researchers because more force is required to cinch the harness. Adjusting each loop in steps is often best (by pulling individual Teflon strands and gradually shortening the harness loops), but researchers should ensure that feathers do not enter the attachment tube or loops because this impedes cinching. A properly fitting harness for a range of bird sizes is impossible to describe with specifics (e.g., loose enough to stick a finger under the tag). Generally, the harness should not restrict bird movement and thus should be a bit loose. However, a harness that is too loose can be lost or result in bird entanglement. We consider a harness to fit well when the loops lay in the groin without signs of pressure on the skin. This can be checked by blowing at the legs while the bird is upside down and moving its legs around. If unsure, we suggest erring on the side of a looser harness, rather than one that is too tight. Once the harness appears to correctly fit, we move the crimp upward to the rear of the tag (and below the antenna or light stalk) to secure the preliminary loop dimensions. We then inspect the bird's belly and legs. If the fit seems too tight at this point, simply reversing the above process loosens the harness (forceps or pliers are helpful for pulling the loop). When satisfied with the fit, we make sure the crimp is at the very posterior end of the tag—below any antennas or sensor stalks. Although the crimp can be placed dorsally where it is easier to work with, the posterior end is safer because the crimp is less likely to catch on vegetation, increase drag, or be easily accessible to the bird. With the crimp in place, we use needlenose pliers to compress it forcefully such that it is flat against the body. In dual-tube tags (Fig. 1), especially on small birds, the crimp experiences relatively weak forces, so cutting off all excess Teflon past the crimp and using a bit of superglue to secure the terminus should be sufficient to secure the harness. For larger birds or tags with rear loop terminals, we often make a single overhand knot at the crimp, then cut away excess Teflon at the knot, and secure the knot with superglue while ensuring that no harsh projections develop that could cause discomfort to the bird ("crusty" knots can be softened by flattening with pliers). In either case, we make sure no loose Teflon ends are present because they can fray, and filaments can catch on vegetation.

Field trial. We tested the harness in the field with several tag types on a diverse group of Amazonian birds. We tracked 60 individuals of 10 non-migratory species that ranged in mass from 21 to 128 g (Table 1) from 2017 to 2019 in primary *terra firme* forest at the Biological Dynamics of Forest Fragments Project (BDFFP) in central Amazonia (Stouffer 2020). In 2017, to detect any effects of tagging in real time (e.g., injury, death, limited activity, and other signs of problems), we deployed VHF radio transmitters (Pip Ag392; Lotek Wireless Inc., Newmarket, Ontario, Canada) on three birds, including two Black-faced Antthrushes (*Formicarius analis*) and one Variegated Antpitta (*Grallaria varia*). Additional birds were tagged in 2017 and 2018 with either archival GPS tags (PinPoint-50, Lotek Wireless Inc.; *Formicarius analis* only) or geolocators (Intigeo-P65B1-11T-20deg; Migrate Technology Ltd., Cambridge, UK). Radio transmitters and GPS tags both had 1.5-mm attachment tubes in the front and rear, with base mass (no harness) of 1.5 g and 2.3 g, respectively. Geolocators had 1-mm attachment tubes in the front and 1-mm metal terminal loops in the back, with a base mass of 0.7 g. All birds were target-netted using playback of conspecific songs to increase our chances of capturing territorial individuals that would remain in the area for recapture. We sought to mark adult males only, but characteristics to differentiate young birds fade quickly in most of our study species and seven are sexually monomorphic (Johnson and Wolfe 2017) with unresolved vocalizations for females. The only *G. varia* fit with a geolocator was a visibly gravid female and we excluded it from mass analyses due to the influence of eggs. At capture, each bird received a tag, metal band, and one or two color bands, and we took standard morphometric measurements, including mass with an electronic balance ($\pm$ 0.1 g; Ohaus, Parsippany, New Jersey, USA, or American Weigh Scales, Cumming, Georgia, USA). We recovered tags $\sim$ 1 yr after deployment by systematic searches and conspecific playback near original capture locations. To minimize the effect of any temporal variation in mass, all birds were captured (and weighed) throughout the day between June and October, which corresponds to the dry season at the BDFFP (Stouffer et al. 2013).

To assess the effect of devices on birds, we compared their body masses in subsequent years. Body mass is a good indicator of condition in birds (Labocha and Hayes 2012), and a lower mass at tag recovery (t_1) than at deployment (t_0) could indicate a deteriorating body condition and thus a possible negative response of birds to wearing devices. Because a change in mass could be the result of environmental stochasticity, rather than due to tags, we compared the body mass of untagged birds that were recaptured in the subsequent year (although all birds captured in 2017 were tagged). We tested for a change in mass in treatment and control groups using separate (one for each group) linear mixed models fitted with restricted maximum likelihood, with mass as a response and period (t_0, t_1) as the explanatory variable, with species as a random effect. Analyses were conducted with package "lme4" (Bates et al. 2020) in R version 4.0.2 (R Core Team 2020).

RESULTS

Observations of radio-tagged birds in 2017 led us to fine-tune the harness configuration. We tracked two of the three birds until the end of the field season (36 and 49 days) and detected no problems, including during visual observations at roost sites. However, one *F. analis* individual died < 1 week after tagging due to an early design flaw, that is, we crimped the Teflon on top rather than behind the tag and left the Teflon ends unsecured to facilitate tag drop, but the ends frayed and Teflon filaments ensnared the bird on a spiny vine. Thus, for subsequent captures, we moved the crimp to the tag posterior (Fig. 1D), trimmed away all excess Teflon, and secured the crimp terminus with superglue. In the end, only two birds were tagged with problematic harnesses—one *G. varia* and one *F. analis*. *G. varia* had no issues (Jirinec et al. 2018), likely due to its larger size and lower propensity to move through dense vegetation.

We detected no problems for recaptured birds with harnesses. Of 90 individuals, we recovered 43 (48%) a year later (Table 1A). Logger deployment and recovery took extensive effort (257 field days) due to the low densities of these species (Stouffer 2007) and sometimes substantial movements, but the probability of recapture varied (Table 1A). None of the recovered individuals had a missing tag at t_1 (359 ± 29 days, mean ± SD), including a *S. caudacutus* tagged twice for a total duration of 700 days. We detected no external injuries such as red skin, although the tips of harness loops were sometimes coated with a bit of dried skin. The body mass of recaptured birds (Fig. 2) did not differ from that when first captured for either the treatment (tagged) group ($\beta = 1.1$, SE = 0.6, $t = 1.9$, $P = 0.07$) or control (untagged) group ($\beta = 0.4$, SE = 0.92, $t = 0.4$, $P = 0.66$). For 11 individuals of six species with geolocators where we weighed the harnesses, mean harness weight was 0.26 ± 0.02 (SE) g, and the weight of the harnesses (Teflon + crimp) of the smallest (Short-billed Leaftosser, *Sclerurus rufigularis*) and largest (Thrush-like Antpitta, *Myrmorthera campanisona*) birds was 0.23 g and 0.29 g, respectively.

DISCUSSION

Tagged and recaptured birds in our study did not lose either their devices or body mass between tag deployment and recovery. In fact, tagged birds were slightly heavier (but not significantly so) at recovery than at deployment, although post-tagging mass increases in a study involving squirrels were interpreted as undesirable effects (Kenward 1982). The results of several studies have revealed a relationship between body mass and life history traits (see Labocha and Hayes 2012 for review). Body mass of Red Knots (*Calidris tenuirostris*) was unrelated to migration departure dates (Battley et al. 2004), but mass was positively correlated with foraging efficiency in American Dippers (*Cinclus mexicanus*; Donnelly and Sullivan 1998), survival of Barn Swallows (*Hirundo rustica*; Møller and Szép 2002) and Eurasian Blue Tits (*Cyanistes caeruleus*; Merilä and Wiggins 1995), and breeding success in Common Terns (*Sterna hirundo*; Wendeln and Becker 1999). Southern Pied Babblers (*Turdoides bicolor*) exposed to unsuitable hot and dry conditions lost mass (Bourne et al. 2020). Thus, a decline in body mass after tagging should indicate that tags were detrimental to birds, but this is not what we detected.

Although species in our study comprised one ecological guild (terrestrial insectivores), this group is taxonomically and ecologically diverse, representing three families with three

Table 1. Summary statistics for field trial of adjustable harnesses: sample sizes per species, duration of wear, and mass of birds at capture and recovery (last three columns are means ± SD)

A. Birds fitted with harnesses and recaptured the following year

Species	Number deployed	Number recovered[a]	Duration (days)	Mass t_0 (g)	Mass t_1 (g)
Myrmoderus ferrugineus (Ferruginous-backed Antbird)	9	4 (44%)	348 ± 59	24.85 ± 0.90	25.90 ± 1.50
Myrmornis torquata (Wing-banded Antbird)	9	3 (33%)	370 ± 3	44.06 ± 0.64	45.60 ± 0.85
Grallaria varia (Variegated Antpitta)[b]	1	1 (100%)	449	127.7	114.0
Hylopezus macularius (Spotted Antpitta)	4	4 (100%)	338 ± 47	41.5 ± 2.31	43.48 ± 2.35
Myrmothera campanisona (Thrush-like Antpitta)	4	4 (100%)	318 ± 22	48.15 ± 2.25	48.60 ± 1.61
Formicarius colma (Rufous-capped Antthrush)	12	5 (42%)	349 ± 37	48.12 ± 1.69	49.60 ± 1.82
Formicarius analis (Black-faced Antthrush)[c]	31	15 (48%)	364 ± 38	62.43 ± 4.02	63.17 ± 3.59
Sclerurus obscurior (South American Leaftosser)	8	2 (25%)	385 ± 35	23.7 ± 0.28	24.20 ± 1.27
Sclerurus rufigularis (Short-billed Leaftosser)	6	2 (33%)	324 ± 13	21.3 ± 1.84	21.80 ± 4.00
Sclerurus caudacutus (Black-tailed Leaftosser)[d]	6	3 (50%)	342 ± 6	38.95 ± 0.78	41.65 ± 1.48
Overall	90	43 (48%)	359 ± 29		

B. Band-only birds recaptured the following year

Species	Number marked[e]	Number recaptured[f]	Duration (days)	Mass t_0 (g)	Mass t_1 (g)
Myrmoderus ferrugineus (Ferruginous-backed Antbird)	18	2 (11%)	350 ± 50	24.70 ± 0.42	24.00 ± 1.84
Grallaria varia (Variegated Antpitta)	1	0	—	128.7	—
Myrmornis torquata (Wing-banded Antbird)	2	1 (50%)	349	45.0	44.1
Hylopezus macularius (Spotted Antpitta)	2	1 (50%)	333	47.9	46.1
Formicarius colma (Rufous-capped Antthrush)	16	2 (13%)	326 ± 84	47.05 ± 3.18	46.75 ± 2.47
Formicarius analis (Black-faced Antthrush)	32	8 (25%)	331 ± 48	61.21 ± 3.14	62.95 ± 3.40
Sclerurus obscurior (South American Leaftosser)	8	2 (25%)	367 ± 2	26.65 ± 0.35	25.25 ± 0.21
Sclerurus rufigularis (Short-billed Leaftosser)	1	1 (100%)	360	19.8	20.3
Overall	80	17 (21%)	345 ± 46		

[a]Values in subsequent columns apply to recovered birds only.
[b]Gravid female at deployment (excluded from condition analysis).
[c]Includes GPS tags (18 deployed, 11 recovered); two birds missing mass at recovery and thus excluded from condition analysis.
[d]Subsequent two columns include one bird tagged twice (total duration = 700 days); we used data only from first recovery for duration and mass; unique birds deployed and recovered = 5 and 2.
[e]Only includes birds in the 2018–2019 cycle; all birds captured in 2017 were tagged.
[f]Band-only birds were not actively recovered (i.e., incomparable with panel A rates).

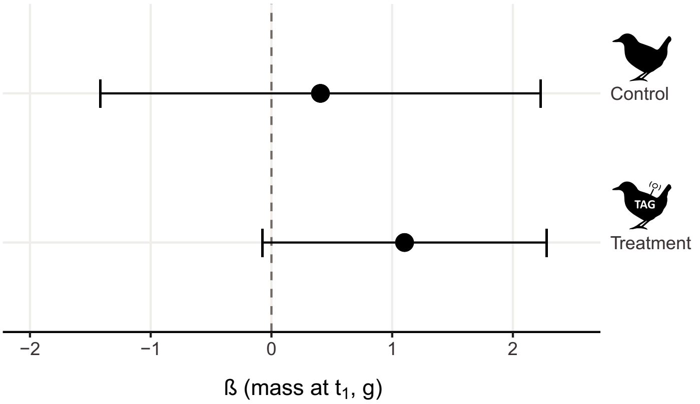

Fig. 2. Bird mass ~ 1 yr after initial marking (t_0). The control group consisted of 17 individuals of seven species marked with bands only, whereas the treatment group included 39 individuals of nine species fitted with tags attached with leg-loop harnesses as described herein. Neither group gained or lost mass at t_1. Points are slope estimates in linear mixed models with error bars representing 95% CI.

distinct body types. Birds retained harnesses despite short tails, upright postures (Grallariidae), and nest placement in underground burrows or tree cavities such as *Sclerurus* and *Formicarius* (Skutch 1969), which may dislodge tags as birds pass through narrow spaces. Antpittas and antthrushes lead a primarily ambulatory lifestyle, a possible concern for a leg-loop harness, but logger recovery rates were highest for these birds. Although all 10 species were resident, non-migratory birds, *Sclerurus* spp. and Wing-banded Antbirds (*Myrmornis torquata*) have large territories (Stouffer 2007). All four of these species prefer to fly, rather than walk, and we encountered long distances between capture locations, including 1.7 km for a South American Leaftosser (*Sclerurus obscurior*), 1.1 km for a Short-billed Leaftosser (*S. rufigularis*), 2.5 km for a Black-tailed Leaftosser (*Sclerurus caudacutus*), and 1.5 km for a Wing-banded Antbird (*M. torquata*). We believe that vagility and large area requirements, rather than mortality due to wearing loggers, were the reasons for our relatively low recovery rates for these species. In every species except for antpittas, birds appeared to become trap-shy and have fluid territories with often high overlap. This, along with the presence of few trails in our study area, translated into challenging conditions for recovery of loggers. Because of the substantial work needed to recapture birds, we did not devote equal effort to both treatment and control birds that would be needed to properly compare the proportion of recovered individuals in both treatment and control groups (Raybuck et al. 2017).

Although we studied resident birds, the harnesses described in our study should be suitable for use with migratory birds as well. The structure of the harness we used is not novel; we simply provide instructions for constructing an adjustable and durable rendering of the harness previously described by Rappole and Tipton (1991) that has been successfully used in many studies of long-distance migrants (Johnson et al. 2012, Macdonald et al. 2012, Thaxter et al. 2014). However, Streby and Kramer (2017) made a distinction between R-T harnesses with two attachment points (“Θ”), which matches our design, and harnesses that more closely resemble the figure-eight in Rappole and Tipton (1991), and raised concerns about the fit of Θ harnesses. Researchers could modify the harness in our study to make a true figure-eight by enlarging the tag’s anterior attachment tube and running steps B and C in Fig. 1 through the front as well, then crimping the Teflon above the tag. However, this would increase drag and, as Raybuck et al. (2017) also pointed out, we currently have little evidence that the figure-eight style is indeed better. Regardless, this debate is probably less relevant for larger birds where the distance between attachment points in Θ harnesses matches the figure-eight style more closely. A more important question may be whether migration-related fattening and the resulting fluctuation in body size are problematic with non-elastic material such as Teflon. Brlík et al. (2020) found higher apparent survival for birds tagged with harnesses made of non-elastic material in their meta-analysis of geolocator studies (and thus mainly migratory birds), suggesting that rigidity is generally not a problem. Tropical residents like our study species lack premigratory fattening, but changes in body mass are still relevant to egg-laying females. That appeared to be the case with our single female *G. varia* that, gravid when first captured, but not when recaptured, weighed 11% less at recapture. Nevertheless, developing eggs seem to extend the vent area while the harness contact points remain unaffected. Concerns associated with elastic harnesses notwithstanding, researchers may substitute Teflon for a stretchable material, but some materials (like Stretch Magic) are not suitable for crimping because that could nip the harness and thus compromise integrity of the loops. Ornithologists need not be reminded about the importance of harness retention, especially for archival loggers or when a single unit can cost over $1000 US.

Our harness design is versatile and can be adapted to various tag types and species. Current configuration of the smallest ICARUS tags (solar light and solar medium; 3.8–4.7 g) has front and back attachment tubes as in Figure 1 (Brigitta Keeves, pers. comm.). In addition to the three types of tags described above, we have used this harness with PinPoint Argos 100 and PinPoint VHF 350 transmitters (5 and 15 g, respectively), both manufactured by Lotek. In an ongoing study, we used the R-T harness described here to tag 14 Barred Owls (*Strix varia*; mean mass = 695 g) before switching to a wing-loop harness that is probably more suitable for this species and larger birds in general. Nevertheless, we did not observe any issues with owls for up to 115 days—the longest period a tag transmitted (i.e., of known fate). Owls often removed tags by breaking the 1.9-mm Teflon, but they also did so with a 1-cm wide, elastic wing-loop harness at comparable rates (V. Jirinec, unpubl. data).

The harness can be modified to work with other tag styles. For example, LifeTags by Cellular Tracking Technologies have front and back loops (holes) rather than tubes. Our design can be adapted to this arrangement—researchers can simply run step A in Figure 1 either around the front or under the tag (ribbon should probably be secured in the front with crimp, glue, or knot to keep the tag centered), then crimping the Teflon behind the tag as described in Results for tags with posterior loop terminals.

Data from loggers placed on individual birds yield invaluable insights into bird biology and technological improvements will likely only increase the number of such studies. Regardless of the device type and exact harness configurations, researchers should make sure that the R-T harness is suitable for their study species, the tag mass is not excessive (Bowlin et al. 2010, Vandenabeele et al. 2014), and the fit is appropriate (not too tight or too loose). Here we present one way to accomplish a good fit—arguably the most challenging aspect of properly attaching devices to birds—thus maximizing bird welfare and the quality of collected data.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher’s website.

Fig. S1. Harnesses ready for deployment on two tag types. On the left, a tag with front and back attachment tubes (PinPoint Argos 100; Lotek). On the right, a geolocator with front tube and posterior loop terminals (Intigeo-P65B1-11T-20deg; Migrate Technology). The geolocator is shown with and without a harness.

Video S1. Harness construction steps for tags with front and back attachment tubes.