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Review

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Harnessing knowledge: A multi-taxa evaluation of device attachment elements, reporting gaps, and protocols for best practices in wild birds

Amy L. Scarpignato,[1,2,#,*] Calandra Q. Stanley,[3,4,#,*] Alexandra M. Anderson,[1] Nathan W. Cooper,[1] Autumn-Lynn Harrison,[1] Valentine Herrmann,[5] Fernando G. López,[1] María E. Rebollo,[6] Kristina M. Delaski,[7] and Peter P. Marra[3,8]

[1]Migratory Bird Center, Smithsonian's National Zoo and Conservation Biology Institute, Washington, DC, USA
[2]Road to Recovery, Earth Commons Institute, Georgetown University, Washington, DC, USA
[3]Department of Biology, Georgetown University, Washington, DC, USA
[4]School of Renewable Natural Resources, Louisiana State University and LSU AgCenter, Baton Rouge, LA, USA
[5]Conservation Ecology Center, Smithsonian's National Zoo and Conservation Biology Institute, Front Royal, VA, USA
[6]Department of Biological Sciences, Virginia Tech, Blacksburg, VA, USA
[7]Conservation Medicine Unit, Wildlife Health Sciences, Smithsonian's National Zoo and Conservation Biology Institute, Front Royal, VA, USA
[8]Earth Commons Institute, Georgetown University, Washington, DC, USA

[#]These authors contributed equally to the paper.

[*]Corresponding authors: Amy Scarpignato, amy.scarpignato@georgetown.edu; Calandra Q. Stanley, cstanley@agcenter.lsu.edu

ABSTRACT

The increased use of bio-logging devices for studies in avian ecology has outpaced the evaluation of device attachment and development of reporting guidelines and protocols that protect animal welfare and data quality. To address this gap, we report on external attachment methods across multiple taxa and define 3 elements, the design, materials, and procedure, that provide a framework to approach device attachment. We conducted a narrative literature review (2010–2022; $n = 1{,}160$ studies) and survey of the ornithological community (2020; $n = 167$ respondents) to assess the use of attachment methods and the reporting of methods and impacts. Harness and mount attachments were used almost equally across the literature and survey. However, 14% of reviewed studies did not report any attachment type and nearly a third lacked sufficient detail to categorize the harness design used. Harness types varied by taxonomic order, with leg-loop and backpack harnesses being the most prevalent and the focus of further analysis. The number of devices deployed was frequently reported in published papers; details on harness and securing material and size were less commonly provided. One fifth of reviewed papers ($n = 269$) using backpack or leg-loop harnesses reported on impacts of attachments, and of those, 58% indicated neutral impacts. By contrast, only 23% of survey respondents reported not encountering impacts in their research. The survey also provided methodological details not found in the literature review, suggesting this knowledge exists outside of the published literature. We emphasize the need for standardized reporting of device attachment methodologies and their impacts on birds. Accordingly, we introduce two illustrated protocols for device attachment. We encourage adaptation for different species and study conditions to support consistency, reproducibility, and ethical, efficient practices ensuring bio-logging remains a key tool for avian research and conservation.

Keywords: backpack harness, bio-logging, device attachment, leg-loop harness, mounts, protocols, reporting, standardization, tracking

How to Cite

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LAY SUMMARY

- Bio-logging has become a standard research tool for studying bird movements and revealing information about demographic rates. As such, there is a need to better evaluate bio-logging methodology, with the goal of minimizing impacts to birds while maximizing data quality.
- We conducted a literature review and survey to assess methods used to attach bio-logging devices to wild birds and evaluate reporting of methods and impacts.
- Harnesses, particularly leg-loop and backpack, were commonly used attachment methods, but their use varied across different bird groups. Although the number of devices deployed was frequently reported, details on harness and securing material and size, and impacts were less commonly provided.
- The survey suggested much knowledge exists outside of the published literature and when not shared with the broader community, limits refinement and reproducibility of methods.
- Our findings emphasize the need for standardization of attachment methods and reporting. Accordingly, we introduce two illustrated protocols for researchers.

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Conocimiento sobre arneses: evaluación multitaxonómica de los elementos de fijación de dispositivos, vacíos en el reporte metodológico y protocolos de mejores prácticas en aves silvestres

RESUMEN

El uso creciente de dispositivos de registro biológico mediante sensores electrónicos (*bio-logging*) en estudios de ecología de aves ha superado el ritmo de evaluación de los métodos de sujeción. Además, ha sobrepasado el desarrollo de guías y protocolos de reporte que garanticen el bienestar animal y la calidad de los datos. Los estudios previos se han centrado en el uso de dispositivos de seguimiento en aves silvestres. Para abordar este vacío de conocimiento, informamos sobre los métodos de fijación externa en múltiples taxones y definimos tres elementos, el diseño, los materiales y el procedimiento, que proporcionan un marco para abordar la fijación de dispositivos. Realizamos una revisión narrativa de la literatura (2010–2022; $n = 1160$ estudios) y una encuesta a la comunidad ornitológica (2020; $n = 167$ personas) para evaluar el uso de diferentes métodos de sujeción y la forma en que se reportan los métodos e impactos. Detectamos que los sistemas de arnés y montaje fueron igualmente comunes tanto en la literatura como en la encuesta. Sin embargo, el 14% de los estudios revisados no informaron sobre ningún tipo de sujeción y casi un tercio carecía de detalles suficientes para categorizar el diseño del arnés utilizado. Observamos que los tipos de arnés variaron según el orden taxonómico, siendo los arneses tipo de lazo en patas (*leg-loop*) y de mochila (*backpack*) los más frecuentes y, por ello, los seleccionamos para un análisis más detallado. Aunque la mayoría de los artículos reportaron el número de dispositivos desplegados, pocos incluyeron detalles sobre el material, tamaño del arnés o métodos de sujeción. Una quinta parte de los artículos revisados ($n = 269$) que utilizaban arneses tipo backpack o leg-loop informaron la presencia o ausencia de impactos, y de estos, el 58% indicó que los impactos fueron neutros. En contraste, solo el 23% de los encuestados reportó no haber encontrado impactos en sus investigaciones; la mayoría clasificó los impactos como de baja o moderada severidad. La encuesta también reveló detalles metodológicos que no encontramos en la revisión bibliográfica, lo que sugiere que este conocimiento existe fuera de la literatura publicada. Destacamos la necesidad de estandarizar el reporte de las metodologías de sujeción y sus impactos sobre las aves individuales. En este sentido, presentamos dos protocolos estandarizados para la sujeción de dispositivos. Promovemos su adaptación según las especies y condiciones de estudio, con el fin de fomentar prácticas consistentes, reproducibles, éticas y eficientes que aseguren que el bio-logging continúe siendo una herramienta clave para la investigación y conservación de aves.

Palabras clave: arnés tipo mochila, fijación de dispositivos, reporte, estandarización, arnés de bucle en las patas, bioregistro, telemetría, protocolos, sistemas de montaje

INTRODUCTION

Recent technological advances have transformed our ability to study the movements and complex biology of a growing number of avian species across their full annual cycles using animal-borne devices (Kays et al. 2015, McKinnon and Love 2018, Williams et al. 2020, Guilherme et al. 2023, Scarpignato et al. 2023). Simultaneously, many bird populations, especially migratory birds, are declining at unprecedented rates, resulting in an urgent need to identify causes of declines and conservation actions to reverse them (Rosenberg et al. 2019, Lees et al. 2022). Bio-logging devices are a key tool for understanding birds' spatial and temporal movement patterns (e.g., habitat use, migration, dispersal) and the environmental and physiological factors shaping these behaviors. These insights are critical for understanding the drivers of populations declines (Wilmers et al. 2015, Yanco et al. 2025) and developing full-annual-cycle conservation strategies (Marra et al. 2015, Flack et al. 2022). As more and longer-lasting devices are deployed (Kays et al. 2015, Geen et al. 2019), there is a need to evaluate the effectiveness of bio-logging approaches, with the goal of minimizing impacts to animals' welfare and behavior while maximizing data collection and quality (Casper 2009, Geen et al. 2019, Longarini et al. 2023, Macey et al. 2025).

Across taxa and study questions, a wide diversity of approaches has emerged for attaching bio-logging devices to wild birds. Evaluation of these approaches requires a comprehensive examination of all components of the device attachment process including capture (e.g., technique, timing and attachment duration), the device itself (e.g., shape, mass, color, antenna), and the attachment method (e.g., design, materials and procedures). While the capture and handling of birds have been extensively evaluated to refine techniques (Bub 1991) and develop ethical guidelines (North American Banding Council 2001, Fair et al. 2023), there are currently no comparable standards for attachment methods. The attachment method is diverse and complex, including both internal (e.g., surgical implantation) and external (e.g., mounts and harnesses) approaches, with the most suitable method depending on the species and study questions (Geen et al. 2019). The multifaceted nature makes it especially important to examine the attachment method in detail as different combinations can lead to varying outcomes. Here, we focus on evaluating three elements of external attachment methods: the design, materials, and procedure. The design (Element 1) consists of 2 features—attachment type and placement. Attachment types include (1) mounts, devices directly attached to a fixed point on the bird's body (e.g., tail mount) or via a support (e.g., leg band); and (2) harnesses, devices indirectly attached to the bird's body through a system of straps that hold or fasten the device to the bird; each of which can have different placements on the bird's body (Figure 1). The materials (Element 2) used to attach devices, are also important to consider, with regards to the mount (e.g., glue, Tesa tape, Beiersdorf AG, Hamburg, DE) or harness (e.g., Stretch Magic [polyurethane elastic cord], Pepperell Braiding, Pepperell, MA, USA; Teflon, Chemours, Wilmington, DE, USA) material as well as the material used to secure the attachment (e.g., thread, glue, crimps). Finally, the procedure (Element 3) used to correctly place and fit the device (i.e., fitting techniques), which should be performed by a trained professional for that species. Across these three elements there is some flexibility to customize attachment methods by selecting from among the different options.

As each of these elements (i.e., design, materials and procedure) can contribute to the cumulative impacts on birds and influence study success (Barron et al. 2010, Bodey et al. 2018, Geen et al. 2019), extreme care should be used when selecting an appropriate attachment method. Studies have found that the attachment design (Biles et al. 2022, Crawford et al. 2026), materials (Brlík et al. 2020 , Clewley et al. 2021a, Fijn et al. 2024), and procedure (Ruder et al. 2012, Mott et al. 2015,

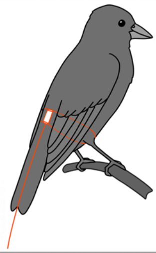
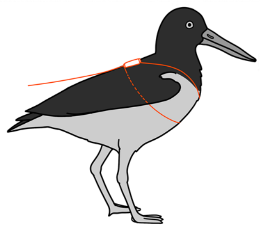
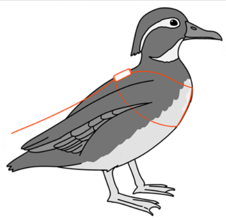
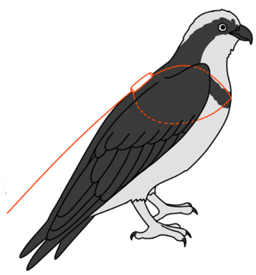
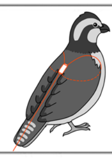
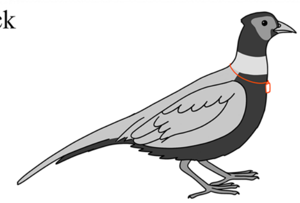
Harness	***Description & Reference***	***Illustration***	***Group***
Device placed on the back on the synsacrum			
*Leg-loop**	Two-loop harness in the shape of a figure-8. The device sits on the synsacrum with two loops placed around the top of the femur, resting in the hip crease; *Rappole and Tipton 1991, Mallory and Gilbert 2008, Streby et al. 2015*		*Passeriformes, Charadriiformes, Accipitriformes, Caprimulgiformes, Cathartiformes, Coraciiformes, Cuculiformes, Falconiformes, Galliformes, Gruiformes, Bucerotiformes, Pelecaniformes, Piciformes, Procellariiformes, Strigiformes, Suliformes*
Device placed on the back between the shoulders			
*Full-body**	Sometimes also called neck loop harness, consists of a smaller loop around the neck and a larger body loop connected by a knot or strap. The harness knot typically sits at the top of the sternum; *Åkesson et al. 2012, Chan et al. 2016*		*Charadriiformes, Accipitriformes, Falconiformes, Anseriformes, Apodiformes, Caprimulgiformes, Cuculiformes, Gruiformes, Passeriformes, Pelecaniformes*
Breast-and-body loop (with or without keel strap)*	Two loops of equal or different sizes, positioned around the body posterior to the wings and anteriorly around the breast. It can be connected ventrally by a short segment of ribbon along the keel; *Dunstan 1972*		*Anseriformes, Charadriiformes, Passeriformes, Pelecaniformes, Procellariiformes, Strigiformes, Suliformes*
*Backpack**	A neck loop and body loop of equal size joined mid-sternum. The neck loop begins at the top of the device and is connected ventrally at the sternum to the body loop that passes under the wings from the back of the device; *Buehler et al. 1995*		*Accipitriformes, Falconiformes, Strigiformes, Anserifonnes, Caprimulgiformes, Cathartiformes, Charadriiformes, Ciconiiformes, Galliformes, Gruiformes, Otidiformes, Passeriformes, Pelecaniformes, Phoenicopteriformes, Piciformes, Podicipediformes, Psittaciformes, Suliformes*
Wing-loop	Two loops that extend under the wings on either side without a central breast strap or loop around the body; *Cooper and Cooper 2013*		*Galliformes, Columbiformes, Passeriformes, Pelecaniformes, Strigiformes*
Device placed on the chest			
Necklace	A loop around the base of the neck positioned over the bird 's crop. The straps connect to the tag, as opposed to the tag built into the material as with a neck collar; *Shields and Mueller 1982, Riley and Fistler 1992*		*Galliformes, Anseriformes, Charadriiformes, Pelecaniformes, Podicipediformes*

FIGURE 1. Description, key references, and illustration of the 6 harness designs included in this study and the groups of birds associated with them within our literature review and survey. We identified a harness as an attachment type that indirectly attaches a device to the bird's body through a system of straps that hold or fasten the device to the bird; each of which can have different placements on the bird's body. Harness displayed sitting on top of feathers for clarity. Asterix (*) denotes additional details about placement of harness and device can be found in Figure 2.

Chan et al. 2016, Mielke and Handschuh 2018) can negatively affect birds through reduced survival, reproductive success, or flight performance and an increased risk of physical injury. Reviews and meta-analyses have also found weak, negative effects of devices on the fitness and behavior of birds (Barron et al. 2010, Bodey et al. 2018, Portugal and White 2022), although most examine device effects in general and are also unable to distinguish what element of the attachment process is driving the negative impact. Despite the many possible combinations of these elements, reviews and individual studies often omit detailed information about the attachment method. This lack of reporting makes it difficult to distinguish which elements were used or assessed and ultimately the underlying mechanism driving negative outcomes. Moreover, the rate of studies evaluating device effects has declined over time (<1% yr^{-1}, Geen et al. 2019), and among studies that do report impacts, many focus on overall effects rather than individual components of the attachment method. These gaps highlight the need to systematically evaluate all elements of the attachment method process through the application of standardized reporting and protocols.

Limited reporting on methods and outcomes of device attachment elements complicates the ability of researchers to make informed decisions about which attachment methods are most appropriate. Decisions will depend on a number of factors including, but not limited to, study questions and duration, device type, and the species' anatomy, physiology (e.g., change in mass, molt) and lifestyle (e.g., mode of locomotion, habitat). Furthermore, attachment methods suitable for some groups of birds may not be for others. For example, surgical methods tend to increase risk of negative impacts on birds (e.g., mortality from anesthesia; Barron et al. 2010, Beaulieu et al. 2010, Geen et al. 2019). However, in diving waterfowl, surgically implanted devices may be preferred to external devices because implanted devices do not disrupt birds' waterproof plumage and have lower drag while flying and diving (Lameris and Kleyheeg 2017). Thus, choice of attachment methods should be tailored to each situation, but decisions about the best methods may be limited by infrequent reporting and a lack of controlled experiments to assess impacts.

Long-term monitoring of individual birds has become increasingly possible with advancements and miniaturization in bio-logging technology, allowing for full-life or full-annual cycle tracking to become a reality for a larger number of species (Scarpignato et al. 2023, Yanco et al. 2025). This likely contributes to the increasing use of long-term attachment methods (Geen et al. 2019). Harnesses are one method used for long-term tracking device attachment that have become more popular for taxa that traditionally did not receive them (e.g., seabirds: Mallory and Gilbert 2008, Thaxter et al. 2014; shorebirds: Chan et al. 2016, Gould et al. 2024), resulting in the development of new harness types and modifications. Although harness use is increasing, they can often be more complex in design and fitting procedure compared to mounts (Weiser et al. 2025). Despite the complexity, the guidance and reporting of best practices for and impacts of the growing diversity of harness designs and modifications remains limited (Geen et al. 2019).

Most often, training and information on best practices for different species remains in grey literature or unpublished within research groups and only accessible through word of mouth (Anderson et al. 2020, Mackenzie et al. 2020, Eldegard et al. 2024). Although sample sizes in any given study are often small, there are now multiple publications reporting impacts of harness attachments (e.g., Thaxter et al. 2016, Lameris et al. 2018, Longarini et al. 2023), results of comparative trials (Thaxter et al. 2014, Scarpignato et al. 2016, Biles et al. 2022, Fijn et al. 2024, Crawford et al. 2026), or modifications in device attachment methods (Chan et al. 2016, Stewart and Millsap 2022); all of which have the potential to enhance both animal welfare and data quality. For example, Chan et al. (2016) alleviated feather shedding by switching to smooth-bottomed devices and modifying the harness material. This example provides evidence for how small changes can result in animal welfare improvements and the importance of improving accessibility to harness designs through publishing methodological details and study results to facilitate continuous improvement (Soulsbury et al. 2020, Longarini et al. 2023).

As the field of bio-logging expands, a key step to ensure the continued evaluation and refinement of device attachment methods is the development of standardized protocols and reporting frameworks. The development of standardized methods for device attachments as well as intentional examination and quantification of impacts would improve reproducibility and oversight by animal care and ethics committees and the humane treatment of wild birds used in research (Soulsbury et al. 2020, Beaulieu and Masilkova 2024). Equally important is encouraging and standardizing the reporting of methods, results and impacts in published papers (Lameris and Kleyheeg 2017, Sequeira et al. 2021, Davidson et al. 2025). Although these practices are common in laboratory settings, they have not been as readily adapted for research on wild animals (e.g., 3 Rs [Replacement, Reduction and Refinement]; Zemanova 2020) and are critical in the development of novel methods or the study of new species. Standardization and reporting ensure both data quality and availability to inform future refinement of animal welfare guidance, while facilitating comparison across studies and taxa.

This is the first study to focus solely on evaluating the reporting of the device attachment process across multiple avian taxa—specifically the elements of design, material and procedure. Our first objective was to investigate the device attachment designs (type and placement; Element 1) used for all groups of birds by conducting a (1) literature review and (2) survey of the ornithological community (hereafter survey). Our second objective was to provide an evaluation of 2 harness types, backpack and leg-loop, the most widely used harness designs from the review and survey. We assess if sufficient information was reported in the primary literature about the methodology, including materials and procedure (Elements 2 and 3), for each harness design and related impacts. We also compare the frequency of reported impacts in the literature with survey responses. Importantly, our aim is not to directly assess impacts, but rather to emphasize the importance of clearly reporting the elements used for an attachment method and whether impacts are present, absent, or cannot be assessed. Our third objective was to support reproducibility and aid in refinement of attachment methods by providing standard, detailed, and illustrated best practice protocols (i.e., standard operating procedures [SOP]) for the design and attachment of these harnesses, backpack and leg-loop, based on work conducted by our research network and information from the survey. Finally, our fourth objective was to suggest reporting guidelines to ensure that knowledge for optimizing device attachment and minimizing impacts to birds is widely shared and available, fostering continued refinement of methods and promoting best practices.

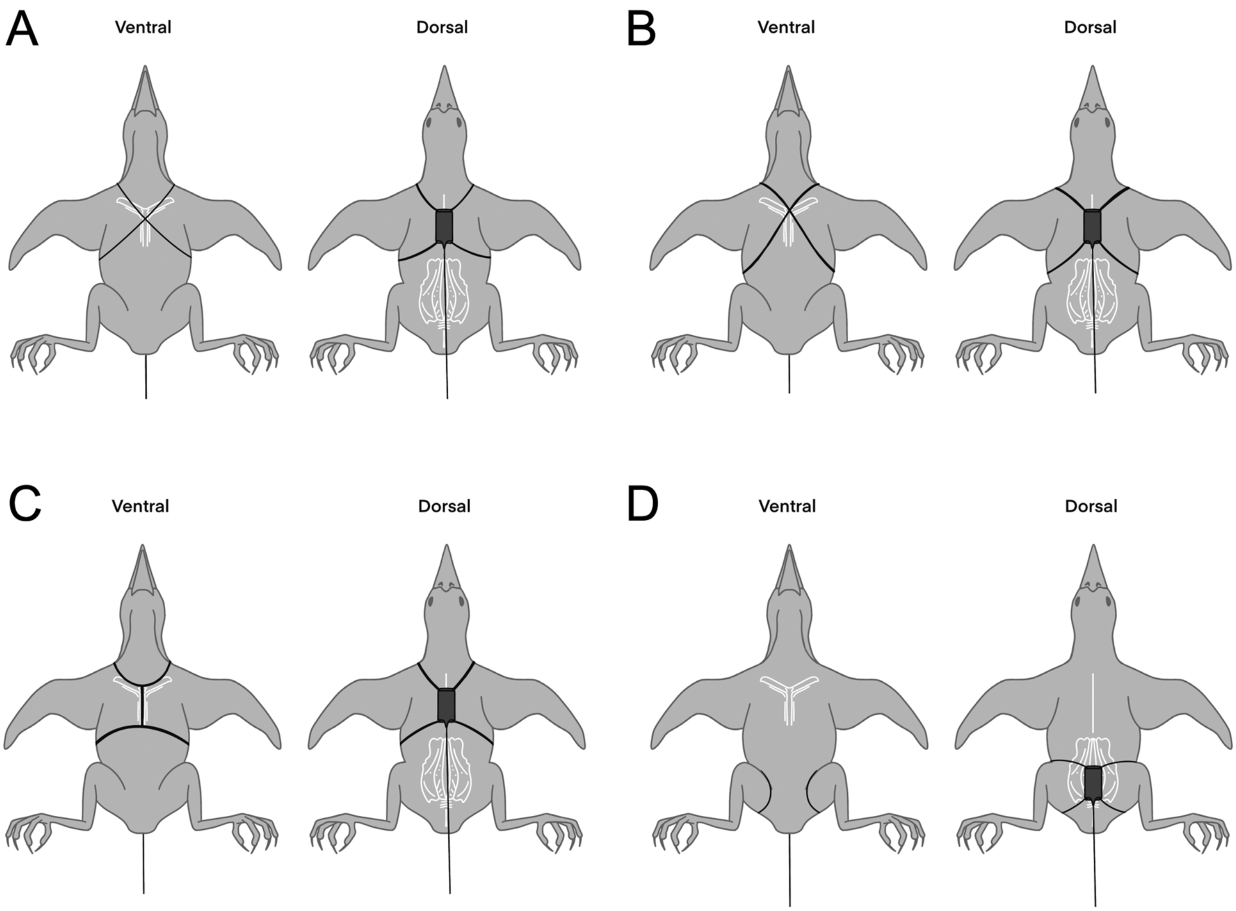


FIGURE 2. Detailed depiction of the 4 harness designs placed on the back of birds: (**A**) backpack, (**B**) full-body, (**C**) breast-and-body, and (**D**) leg-loop. Designs differ based on position of the device on the back and the placement of harness straps and cross points relative to the sternum, wings, and hips. Device sits on the back (**A–C**) between the wings or (**D**) on the synsacrum. Full-body harnesses (**B**) have a smaller loop around the neck and a larger loop around the body with a ventral cross point that sits mid-sternum, whereas a backpack harness (**A**) has 2 roughly equal sized loops around the neck and body with a ventral cross point that sits at the top of the sternum. Note: harness design shown on the same bird model for clarity; see Figure 1 for groups of birds associated with each harness design.

METHODS

Attachment Design

Names for attachment design vary in the literature and in common usage. For consistency in categorizing attachment designs across the literature review and survey, we defined a standard naming practice for common attachment designs according to type and placement. Internal attachment methods included implants. External attachment methods included harnesses and mounts. As above, we defined a harness as a system of straps that hold or fasten a device indirectly to the bird's body. We categorized harness designs previously described in the literature according to (1) the placement of the device and (2) the location of the harness straps on the bird's body (Figures 1 and 2). This included leg-loop, full-body, breast-and-body loop (with or without keel strap), backpack, wing-loop, and necklace harness (Figure 1). For harnesses where devices are placed on a bird's back, a number of types exist that are largely differentiated based on the location of the harness straps relative to the sternum, wings, and hips (Figure 2). We defined a mount as a technique whereby the tracking device is directly attached to a fixed point on the bird's body, or via a support (e.g., device affixed to a leg band [tarsal mount] or device built into the material [neck collar]). We categorized mounts as neck collars, leg and tarsal mounts, glue, Tesa tape, or sutures.

Literature Review

We conducted a narrative literature review of English language peer-reviewed publications in *Web of Science* published over a twelve-year period from 2010 to 2022 to determine attachment designs currently in practice. This period coincides with the "golden age" of animal tracking (Kays et al. 2015) and the miniaturization and increased use of tracking technologies (Geen et al. 2019, Scarpignato et al. 2023) making it a suitable timeframe for our study. Search terms included: (*track* OR tag* OR *transmitter* OR *telem* OR *logger* OR transpond* OR collar* OR geolocator* OR gps OR nano* OR gsm OR biologging* OR argos) AND (*bird* OR avian* OR raptor* OR waterfowl*). We included "raptor" and "waterfowl" as separate search terms because other groups (e.g., shorebirds, seabirds, songbirds, wading birds) were already

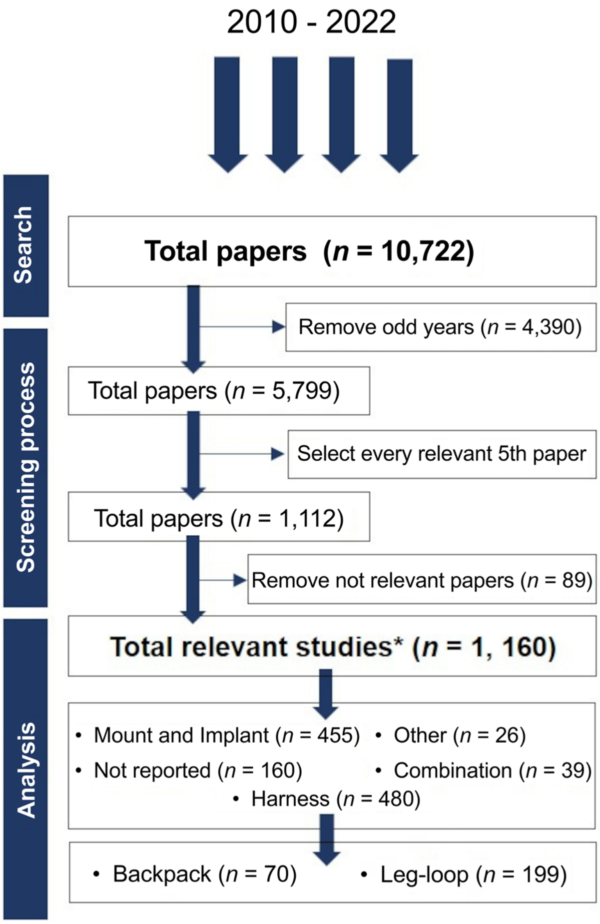


FIGURE 3. Narrative literature review workflow. The process begins with the search phase, continues through the screening process, and concludes with the analysis. The literature review process resulted in 1,112 papers and of those, 89 were not relevant to our review (studies that deployed tracking devices versus studies analyzing previously collected tracking data). *Multiple attachment designs were sometimes reported within one paper; counting each design as a sample yielded 1,160 studies.

captured by the term "*bird*". Due to the high volume of papers returned by this search ($n = 10{,}722$), we focused on even number years (i.e., 2010, 2012, 2014, 2016, 2018, 2020, 2022) and retained every fifth paper (Figure 3; see Supplementary Material 1 Methods for detailed sampling protocol). This subsampling approach has been used in previous literature reviews (e.g., Driscoll et al. 2014, Stevens et al. 2023). Our search was not intended to be comprehensive but to sample the literature broadly to provide a representative sample for comparison of common attachment designs in use during the time period.

Data inclusion

For each paper, we reviewed the introduction, methods, and results and extracted the following information: relevance to this study (i.e., bio-logging of birds), taxonomic order, taxonomic family, species, type of tracking device, attachment design and citation for the attachment design. We classified attachment designs (Element 1) to the standardized definitions above using descriptions and references provided by the authors of each paper. For studies using either a leg-loop or backpack harness, we further classified whether the paper reported information about the elements of the attachment method in the following categories: reason attachment method was chosen (Element 1); harness material, harness material size, and securing material (Element 2); and fitting method (Element 3), number of devices deployed (versus retrieved or transmitting), and device and harness weight. We also classified whether papers reported on impacts. Only papers that explicitly referred to impacts of the attachment method were included, and we further categorized the impacts as negative, neutral (the authors evaluated impacts, but none were found), or uncertain if we could not assign the impact as neutral or negative from the author's description (Supplementary Material 2). We relied on the author's description of the impact to determine if it was related to the attachment method; however, it can be difficult to disentangle the impacts of the attachment method from those of the device, making it unclear in some cases which factor was responsible, or the number of individuals affected.

Survey of the Ornithological Community

To explore information the ornithological community may not include in peer-reviewed papers, we coordinated an anonymous online survey using *Google Forms* (conducted July to September 2020) to gather additional insight into the choice of the elements of harness attachment methods (design, materials, and procedure), as well as any impacts encountered or evaluated while using each attachment design (see Supplementary Material 1 Appendix 1). We chose to conduct an anonymous survey to encourage participation without concern that reporting could impact research capacity or lead to loss of permits. The questionnaire consisted of open-ended or select-all-that-apply questions repeated for each attachment design and species or taxonomic order (see Supplementary Material 1 for questionnaire). To avoid limiting responses to predetermined options, select-all-that-apply questions also included the option to provide additional information. Respondents selected the attachment design from a list that included the types and definitions above and shared insights from their experience. This included the harness and securing materials used, the factors considered in their selection, and the evaluation of impacts. We advertised the questionnaire in English across social media platforms (Twitter, Instagram) and targeted listservs (Movebank, International Bio-logging Society, Ecolog).

Data Analysis

Attachment design

Based on the results of the literature review and survey, we summarized the number of studies using each attachment design and categorized them as harness versus mount and implant, as the remaining analyses are focused on harness attachment methods. We then summarized the percent of harness designs used to attach devices to different orders of birds.

Leg-loop and backpack harness

We conducted further analyses for the 2 most commonly used harness designs encountered in our literature review, survey, and other reviews (Geen et al. 2019, Gould et al. 2024). We used an adjusted Pearson's chi-square analysis with bootstrap simulated *P*-values (10,000 replications) to determine whether taxonomic order was associated with the use of harness type (backpack and leg-loop), in both our literature review and survey. We removed any taxonomic order from the analysis with expected counts <5. To assess if sufficient methodological information about attachment design (Elements 1), materials (Element 2), and procedures (Element 3) is reported for studies using leg-loop or backpack harnesses, we summarized the percent of papers that reported the categories described in the data inclusion section. To determine if the reporting of methodological information was associated with harness type (backpack and leg-loop), we used an adjusted Pearson's chi-square analysis with bootstrap simulated P-values (10,000 replications). We summarized the frequency of impacts (neutral, negative, or uncertain) reported if the paper explicitly referred to impacts of the attachment. As stated above, we relied on the authors' descriptions to assess if impacts could be attributable to harness design. Separating an impact of the attachment method from the device is often challenging, leaving it unresolved in some cases which factor was responsible. To compare the frequency of impacts between the literature review and survey, we collapsed the categories of impact severity (low, modest, high, very high) provided by survey respondents (Supplementary Material 1 Appendix 1) to: no impact, impact observed, and uncertain (unsure if an impact was observed). Lastly, we summarized and identified the most commonly selected harness and securing material survey respondents reported using for backpack and leg-loop harnesses, as well as factors considered when selecting materials.

All data collation, preparation, and analysis were performed in R (R Core Team 2025). Chi-square analyses were performed in the R package *chisquare* (Alberti 2024). We considered $P < 0.05$ a statistically significant difference and examined standardized residuals (|residual| > 2) to indicate significant deviations from the expected count.

RESULTS

Attachment Design

Our literature search criteria resulted in 1,112 papers, and of those, 1,023 were relevant to our review (i.e., studies that deployed tracking devices versus studies utilizing previously collected tracking data; Figure 3). Multiple attachment designs (Element 1) were sometimes reported within one paper; counting each design as a sample yielded 1,160 studies across 27 taxonomic orders (Supplementary Material 1: Figure S1), which were broadly grouped as harness (41%; $n = 480$) or mount and implants (39%; $n = 455$). We found that 3% ($n = 39$) of papers utilized multiple attachment designs within one harness or mount (e.g., a device that was glued and sutured), which we categorized as "combination". We categorized 2% ($n = 26$) of papers as "other" because they did not meet any of our attachment design descriptions (i.e., custom design). Additionally, 14% ($n = 160$) of papers did not report or provide citations to indicate the attachment design and were categorized as "not reported" (Supplementary Material 1: Figure S1).

A total of 175 individuals responded to our survey, and of those, 170 used an attachment category relevant to this paper (i.e., a mount, implant, or harness). Respondents who completed the survey but did not report an avian species or taxa were removed from the analysis ($n = 7$ responses), resulting in a total of 163 respondents. Respondents were able to report on their experience with multiple attachment designs; therefore, the number of responses for each attachment design varied across the survey. On average respondents reported 2 ± 0.09 designs (range: 1–6), with 106 respondents having experience with multiple design types. This resulted in 404 responses for attachment design across 25 orders of birds (Supplementary Material 1: Figure S1). Over a third of respondents reported on multiple taxonomic orders ($n = 59$, mean: 1.5 ± 0.07, range: 1–6). Overall, use of mounts and implants (59%; $n = 233$) were reported more in the survey than harnesses (41%; $n = 163$), while 2% ($n = 8$) were categorized by respondents as "other" for being custom attachment designs that did not meet any of our descriptions. Overall, the results of our literature review and survey yielded a similar distribution of studies across taxonomic orders as other reviews examining general device effects (Geen et al. 2019, Bodey et al. 2018) and general rates of tracking across taxonomic orders (Guilherme et al. 2023, Scarpignato et al. 2023).

Harness design

The literature review revealed that leg-loop (41%, $n = 199$) and backpack (15%, $n = 70$) harnesses were the most commonly used harness design (Element 1), followed by necklace (6%, $n = 27$) and breast-and-body loop (4%, $n = 21$) harnesses (Figure 4). We categorized a large proportion of harness designs (31%, $n = 149$) as "unknown back harness" due to insufficient information about the design, specifically the placement of the harness straps relative to the sternum, wings, and hips (Figure 2), which prevented accurate classification of the harness and precluded these studies from further analyses. Similarly, from the survey, leg-loop (47%; $n = 76$) and backpack (21%; $n = 34$) were the most frequently used harnesses, followed by breast-and-body loop (11%; $n = 18$) and full-body (14%; $n = 22$) harnesses (Figure 4). The necklace (survey, 4%; literature review, 6%) and wing-loop harnesses (survey, 4%; literature review, 1%) were not well represented in either sample (Figure 4).

Harness use and type varied across taxonomic orders for both the literature review and survey (Figure 5). The proportion of taxonomic orders represented in the literature and survey differed (e.g., survey better sampled Charadriiformes and literature review better sampled Passeriformes; Figure 5), however, general patterns within orders were largely consistent. Passeriformes, Accipitriformes, Charadriiformes, Anseriformes, and Galliformes were more likely to receive harnesses than other orders. The inability to identify harness types (i.e., unknown back harness category) occurred across most orders in the literature review ($n = 21/24$; Figure 5). Among studies where harness type could be identified, the backpack harness was the most commonly used harness for Accipitriformes, Falconiformes, and Strigiformes, while the breast-and-body harness was dominant for Anseriformes, and the necklace harness for Galliformes. The leg-loop harness was the dominant harness design across several orders (e.g., Passeriformes, Caprimulgiformes, Charadriiformes, and Piciformes). However, certain taxonomic orders showed little (e.g., Strigiformes, Ciconiiformes) or no (e.g., Anseriformes) use of leg-loop harnesses across both sources. Some taxonomic orders showed use of multiple harness designs, including Anseriformes (breast-and-body and backpack), Charadriiformes (leg-loop, full-body, and backpack), and Procellariiformes (leg-loop and backpack; Figure 5). The dominant harness design remained uncertain for several orders (e.g., Bucerotiformes, and Cuculiformes; Figure 5) because harnesses are used infrequently compared to other designs (Supplementary Material 1: Figure S1) or overall rates of tracking are low (Geen et al. 2019, Scarpignato et al. 2023).

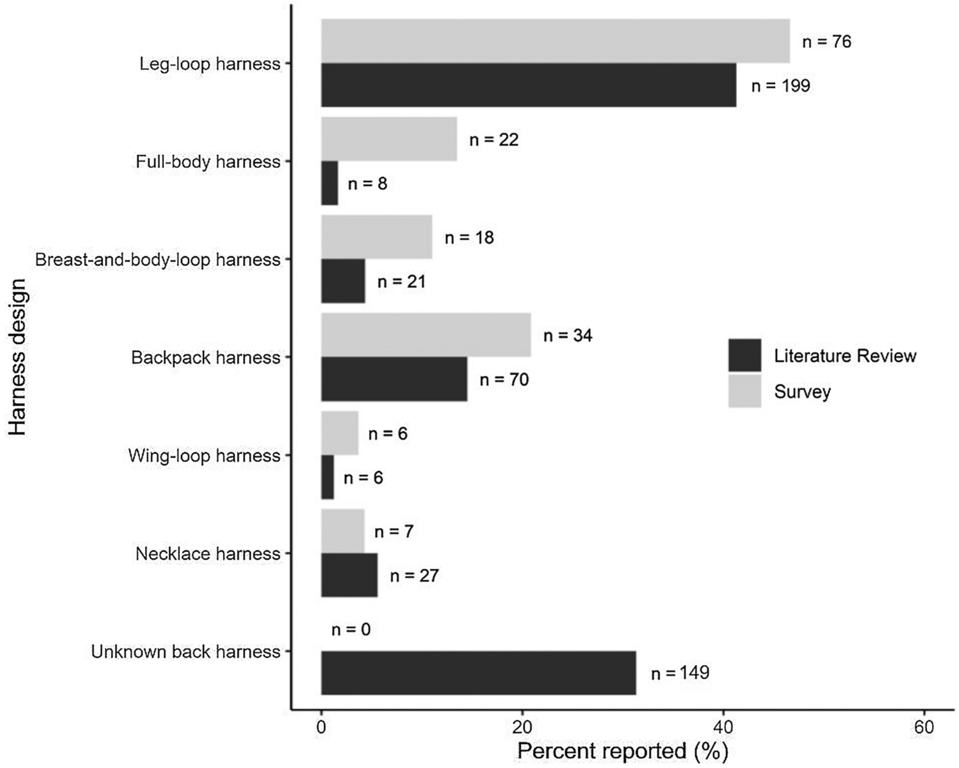


FIGURE 4. Percentage of published studies found in our literature review ($n = 480$; black) and survey responses ($n = 163$; gray) employing different harness attachment designs across all avian taxonomic orders.

Leg-Loop and Backpack Harness

Of the 24 taxonomic orders using harnesses, 21 were not included in the chi-square analysis due to small sample size from a combination of factors, including the inability to assign harness design (i.e., unknown back harness; Figure 5) or use of other attachment designs (Supplementary Material 1: Figure S1), and overall limited tracking studies in those orders (Geen et al. 2019, Scarpignato et al. 2023). Leg-loop and backpack harness use differed significantly among taxonomic orders, with certain orders more likely to receive a specific harness design (literature: $\chi^2_{adj} = 108.75$, df = 2, $P < 0.001$, $n = 212$; survey: $\chi^2_{adj} = 35.25$, df = 2, $P < 0.001$, $n = 75$). Accipitriformes were fitted with a backpack harness more than expected and a leg-loop harness less than expected (literature: |residual| = 9.42; survey |residual| = 5.98). In contrast, Passeriformes were more frequently fitted with a leg-loop harness and less frequently with a backpack harness than expected (literature: |residual| = 9.10; survey |residual| = 3.11; Supplementary Material 1: Table S1). Interestingly, the literature review indicated Charadriiformes were fitted with a backpack harness more than expected and a leg-loop less than expected (|residual| = 2.56), whereas the survey showed the opposite (|residual| = 2.49; Supplementary Material 1: Table S1).

Reporting of methodological information

In the reviewed studies using leg-loop and backpack harnesses, most addressed attachment design (Element 1) and reported the reference describing the attachment design (backpack 90%, leg-loop 82%) but few studies provided information on why the selected harness design was chosen. For materials (Element 2), most studies reported the harness material used (backpack 85%, leg-loop 57%; Figure 6), 37% of studies using a backpack harness reported the harness material size, compared to 25% of leg-loop harness studies, and few studies provided information on the type of securing material used. For procedure (Element 3), most reported the number of devices deployed (backpack 97%, leg-loop 95%). Approximately one third of studies reported the combined weight of the device and harness (backpack 38%, leg-loop 34%). Few studies provided information on the fitting methods (5–20%; Figure 6). There was a significant association between harness type (backpack and leg-loop) and the reporting of methodological information ($\chi^2_{adj} = 16.55$, df = 8, $P = 0.04$, $n = 269$). Studies using backpack harnesses reported the reason for selecting the harness type more frequently than expected, while studies using leg-loop harnesses reported this information less frequently than expected (|residual| = 2.79; Supplementary Material 1: Table S2). Other methodological factors did not contribute significantly to the overall chi-square statistic, suggesting that reporting practices, although low, were consistent regardless of the harness design used (|residuals| < 2; Supplementary Material 1: Table S2).

The survey provided additional methodological information about the most commonly selected harness design (Element 1) and securing material (Element 2) used for backpack and leg-loop harnesses, as well as factors considered when selecting materials and developing methodologies (Elements 2 and 3). Similar materials were reported being used by respondents in the survey for both backpack and leg-loop harnesses, yet some differences emerged. The dominant harness materials used for leg-loop harnesses were Stretch Magic, Teflon and elastic cord, while researchers using backpack harnesses largely used Teflon (Supplementary Material 1: Table S3). The dominant securing materials for both harness designs were glue, knots, and crimps; however, sewing was also common for securing

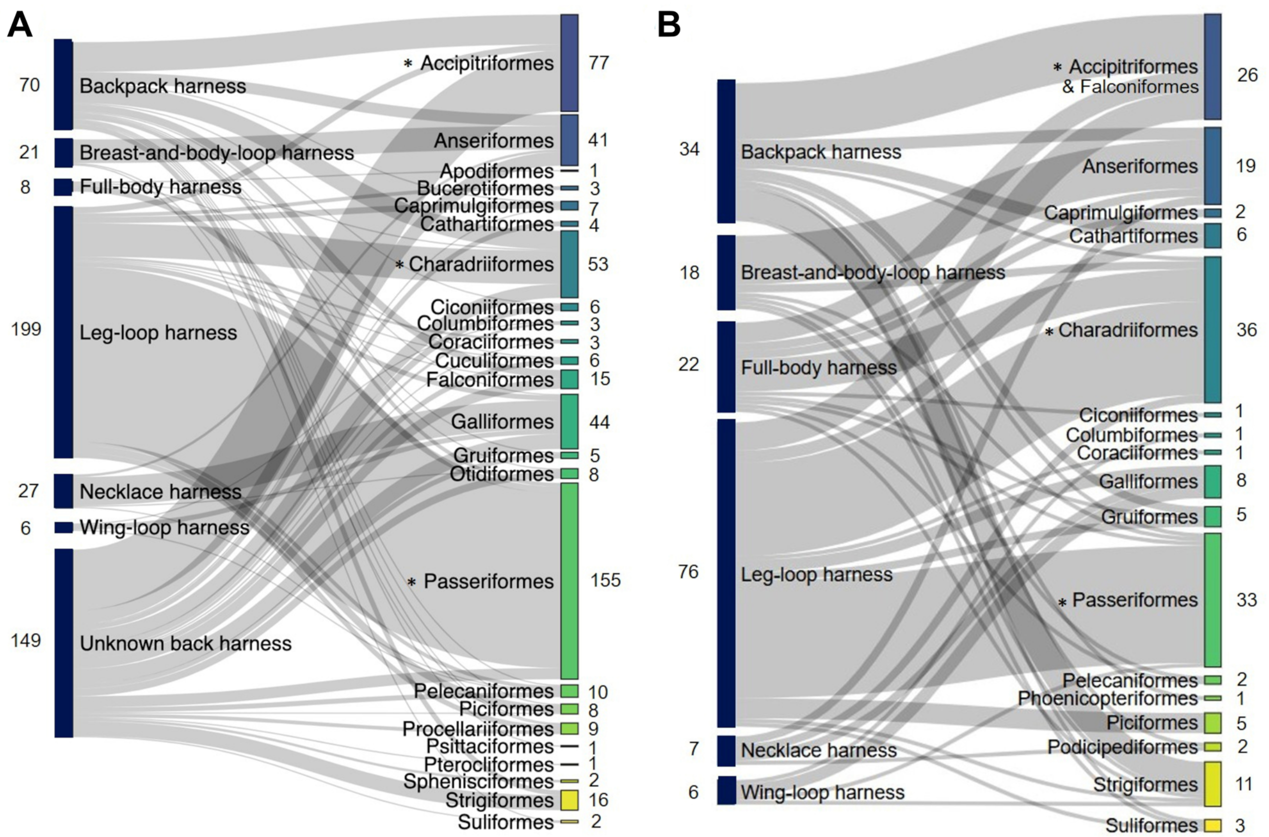


FIGURE 5. Sankey diagram (alluvial plot) showing the proportion of harness designs (left side) used to attach devices to different avian taxonomic orders (right side) in our (**A**) literature review ($n = 480$) and (**B**) survey of the ornithological community ($n = 163$ responses). Height of the bars represents the proportion of harness designs, and the number next to the bar represents sample size. Thickness of connections represents the proportion of studies or survey respondents that deployed a harness design on the corresponding taxonomic order. Asterix (*) denotes orders with sufficient sample sizes for analysis of methodological reporting.

backpack harnesses (Supplementary Material 1: Table S3). For both backpack and leg-loop harnesses, the top considerations for choosing harness and securing materials (Element 2) selected by respondents included strength and durability, tracking duration, and the bird's weight and size (see Supplementary Material 2–5 for more considerations). The ability to customize fit was also an important consideration when choosing the securing material for both harness types. For leg-loop harnesses, logistical factors such as attachment time, ease of application, and device type were frequently selected. For backpack harnesses, respondents frequently selected the bird's ability to pull at the harness and the inclusion of a breakaway point. Logistical factors were selected more often than life-history traits (e.g., reproductive strategy, life span, foraging method) as considerations for both harness types. Although previous experience was not provided on the list of considerations in the survey, some respondents included it as a consideration for harness and securing materials across both leg-loop and backpack harnesses.

Reporting of impacts

In our literature review, 21% of the reviewed studies ($n = 56$ studies; Figure 6) using backpack or leg-loop harnesses reported on impacts (neutral, negative, or uncertain) to birds; reporting was similar across harness types (backpack 20%, leg-loop 24%). Multiple impacts were often evaluated within one paper; counting the combination of each impact and rating (neutral, negative, or uncertain) within a paper yielded 91 reported impacts. Of the reported impacts, 58% reported a neutral impact, 40% a negative impact, and 2% uncertain (Supplementary Material 1 Appendix 1). By contrast, survey responses (leg-loop: $n = 76$; backpack: $n = 41$) indicated that impacts from harnesses occur more frequently (Supplementary Material 1: Appendix 1: Figure S1) than reported in the literature; 72% ($n = 84$) reported observing impacts, compared with 23% ($n = 27$) who reported no impacts, and 5% ($n = 6$) who were uncertain.

DISCUSSION

This paper is the first to explicitly assess device attachment methods used and reported by scientists for studying wild birds across multiple taxa, with a focus on 3 elements: attachment design, materials, and procedure. A narrative literature review of a sample of studies from the last 12 years and a survey of ornithological researchers revealed that harnesses and mounts are both commonly used to attach tracking devices to wild birds. However, there are notable inconsistencies and gaps in the reporting of attachment methods with 14% of all papers failing to report the type of attachment used. Both our literature review and survey confirmed that harnesses are used across a wide taxonomic diversity of birds, but the type of harness designs used varied across taxonomic order. Our review identified further inconsistencies and gaps in the reporting and naming

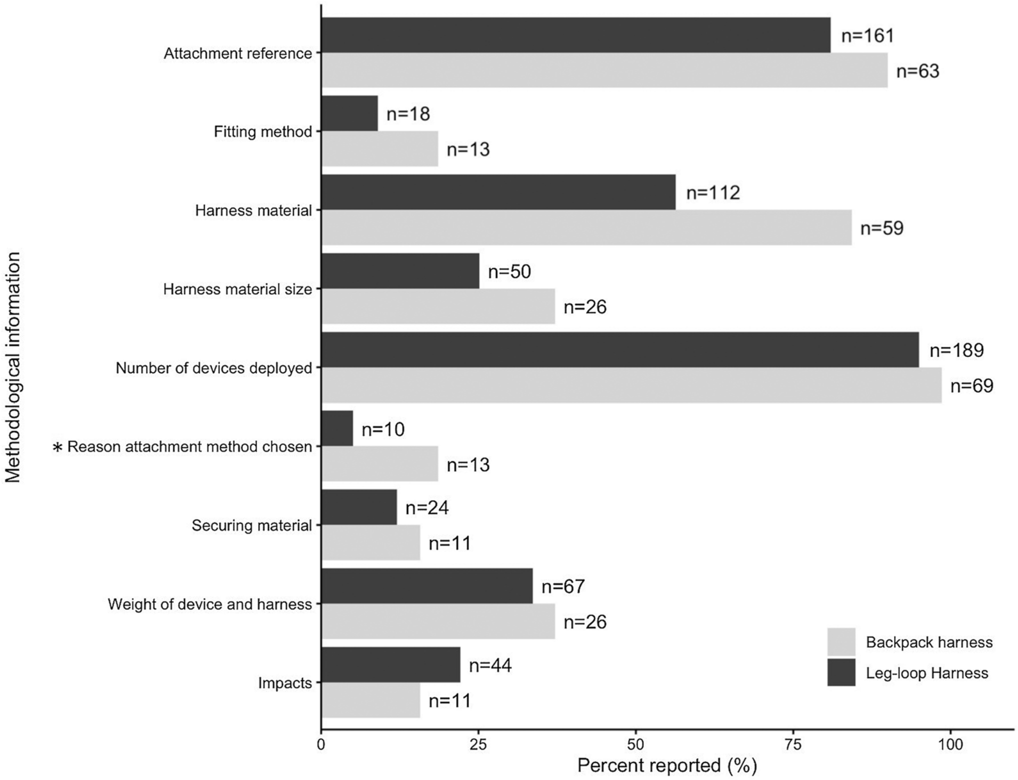


FIGURE 6. Proportion of published studies from our literature review using backpack ($n = 70$; light gray) or leg-loop harnesses ($n = 199$; dark gray) reporting information about methodologies or device attachment impacts (neutral, negative, or uncertain). Asterix (*) denotes a significant deviation from expected counts.

conventions of harness designs, as well as methodologies and impacts. This made it difficult to determine and/or fully evaluate designs used and highlights the importance of thorough and standardized reporting to assess attachment techniques to improve study outcomes and animal welfare. The elicitation of input through our survey provided additional information about harness attachment methodology and impacts not found within the studies in our literature review. Our findings offer valuable guidance, based on a representative—not exhaustive—analysis of current device attachment methods across taxa.

The use of different harness designs varied across and within taxonomic orders in both our literature review and survey, but few studies we reviewed provided explanations for their choice of harness design. Leg-loop harnesses likely offer advantages such as providing a secure attachment with minimal flight interference by avoiding the wings, pectoral muscles, or fat deposits (Thaxter et al. 2014), allowing for adaptability to fluctuations in body mass (Gould et al. 2024), and reducing drag (Longarini et al. 2023). They also require less material, making them lighter and more suitable for smaller species. By contrast, the backpack harness positions the device closer to the center of gravity in flight, minimizing aerodynamic effects, despite its increased drag and energy demands (Vandenabeele et al. 2014, Longarini et al. 2023). Backpack harnesses may also be preferred for species with short thighs (Longarini et al. 2023), strong beaks that could reach and damage the harness (Thaxter et al. 2016), or where feather interference with solar panels is a concern (Thaxter et al. 2014). The mixed use of harness designs in groups such as Charadriiformes and Anseriformes, likely reflects the need for flexibility due to their diverse morphologic shapes, behaviors, and ecological requirements (Geen et al. 2019, Longarini et al. 2023, Gould et al. 2024). Low tracking rates (e.g., Coraciiformes, Podicipediformes; Scarpignato et al. 2023) or higher use of mounts as compared to harnesses (e.g., Suliformes, Procellariiformes; Supplementary Material 1: Figure S1) precluded these orders from our analysis. Overall, the variation in harness designs across different bird groups highlights the importance of selecting attachment methods tailored to a species' biology (e.g., foraging behavior, locomotion) and study objectives (e.g., tracking duration) and of reporting outcomes to inform refinement and best practices.

Lack of Standardized Naming Convention

Inconsistent naming conventions across studies meant we were unable to categorize the harness design for nearly a third of all publications reviewed. This was due to the lack of standardized terminology, ambiguous or inconsistent descriptions, and/or lack of citations, particularly for harnesses placed on the backs of birds. We propose that instead of simply describing the placement as "a tag was placed on the back of the bird", researchers use a standardized naming convention for harnesses to reduce confusion. Specifically, we propose a naming convention based on the placement of the device and harness on the body of the bird, with an emphasis on the placement of the harness straps (Figures 1 and 2). Due to the similarity of many harness designs, we provide anatomical illustrations to aid in differentiation between harness designs, especially between harness designs placed on birds' backs (e.g., backpack, full-body, and breast-and-body loop; Figure 2). This straightforward and intuitive system aims to improve clarity in reporting about the use of device attachment methods and enhance the evaluation and refinement of attachment designs across species.

Reporting Challenges

Methodological information

Another major issue identified in our literature review of backpack and leg-loop harnesses was the inconsistent reporting of methodological details. Key information, such as the harness and securing materials, fitting procedures, and the combined weight of the device and harness, was often missing or insufficiently detailed. By contrast, nearly all papers reported the number and type of devices deployed, suggesting that while attachment details may be omitted, sample size is considered essential for publication. Many studies, especially those using leg-loop harnesses, did not include explanations for attachment design choices, limiting their reporting to a citation without further methodological justification. Commonly used attachments are often assumed to require minimal justification or explanation beyond a citation (Geen et al. 2019). However, citing a reference does not always provide the detailed methodological information that would be most useful to researchers, such as why a harness was chosen. While the majority of studies provided a reference for the attachment design, this result is likely an overestimate, as we could often only confidently categorize devices as placed on the back when a citation was provided. A previous analysis of tracking studies also found that critical details necessary for reproducibility and attachment analysis were absent in over half of the studies (Geen et al. 2019). Ultimately, the lack of standardized reporting limits our understanding of current practices and hinders the ability to make evidence-based recommendations for refining harness designs to minimize potential impacts (Bodey et al. 2018, Geen et al. 2019).

Recognizing the importance of methodological information is essential to encourage its inclusion and standardization in future published studies. Our survey provided valuable methodological insights that were not accessible through the literature review alone, reinforcing the idea that much knowledge exists outside of the published literature. Many survey respondents identified key considerations in selecting appropriate attachment methods and noted ongoing efforts within their research groups to refine these methods. This underscores that important methodological information is often shared informally or through alternative approaches rather than through the published literature, making its dissemination important to ensure accessibility for other researchers. This is especially important for those working with different taxa where methods could be adapted or in locations without access to the same training opportunities or research networks. While calls for the standardization of bio-logging data are critical (Sequeira et al. 2021, Davidson et al. 2025), here, we also emphasize the need to standardize the reporting of methodological information. This shift is essential for improving data reliability, promoting animal welfare, refining established methods (e.g., 3Rs; Zemanova 2020) and facilitating meta-analyses about the effectiveness of attachment methods (Bodey et al. 2018, Geen et al. 2019). We recommend key methodological details and rationale for selecting different harness designs should be standard for scientific journals and explicitly reported within the methods section or as supplementary material (see Box 1). Online repositories like Movebank (Kays et al. 2022), which provides attribute fields for the attachment method, could serve as platforms for storing this information. Ensuring such information is readily accessible will improve the reproducibility and comparability of tracking studies and drive continuous refinement of attachment methods, ultimately advancing best practices in device attachment and improving outcomes for birds.

Harness impacts

Our literature review revealed infrequent (21%) reporting of the impacts of backpack and leg-loop harnesses, which is similar to infrequent and decreasing rates of reporting found in previous studies broadly focused on device impacts (Barron et al. 2010, Geen et al. 2019). By contrast, our survey of the ornithological community using leg-loop and backpack harnesses revealed that researchers may be encountering impacts of these harnesses on birds more frequently than reported in the literature. Similarly, a survey of banders permitted to deploy devices on birds in the United States and Canada found that only 5% of researchers that had encountered effects of devices (negative impacts or damage to devices) had published their encounters in peer-reviewed journals (Hill and Elphick 2011). There are likely a multitude of factors contributing to low reporting rates of impact assessment, including low sample sizes or recapture rates preventing monitoring for and identification of a problem, its cause and extent, and limiting the ability to publish, or fear of losing permissions to deploy devices if impacts are reported. The lack of reporting on impacts in peer-reviewed publications discovered in our literature review, together with incomplete reporting on methodologies makes the comprehensive and evidence-based evaluations of harness designs difficult. However, the response to our survey and other surveys (Hill and Elphick 2011), suggests that this information is important for improving device attachment methodologies and making this information available would facilitate the comparison and evaluation of different techniques in future meta-analyses and welfare guidelines (Box 1). The low reporting also suggests some researchers may be unaware of the potential adverse impacts associated with some harness designs. If this information remains largely available through word of mouth, it hinders the development of appropriate experiments to test for alternative methods and/or designs to minimize impacts.

The task of increasing access to information that improves animal welfare and research outcomes in bird device attachment studies, such as trainings, developing and sharing protocols, reporting on successful and unsuccessful attachment methods, and expanding a standard framework for reporting methods and results of device attachment (see Box 1), would ideally be managed by permitting offices. For example, the United States Geological Survey Bird Banding Laboratory (BBL) sends out memos if alerted about a negative impact from a particular attachment method. Yet, until standardized reporting practices are more established and accessible, we highlight several actions researchers should adopt. First, we encourage editors and reviewers to require the inclusion of this information for all studies using attachment devices on birds and to encourage publication of papers or short notes when no or negative impacts are encountered (e.g., Stewart and Millsap 2022, Souc et al. 2024, Lopez et al. 2024). Collecting and reporting information systematically will provide the data necessary to identify patterns that could indicate a problem or the

Box 1: Guidelines for standardized reporting of attachment methods and outcomes, with recommendations for preparation and trainings to improve reproducibility and animal welfare.

Standardization and Reporting

Harness Naming Convention

- See Figure 1 & 2

Protocols

What to Report

- See Supplementary Material 2 – 5
- Controlled trials of harnesses (captive or wild)
- Example: *In our first year, we conducted a pilot study testing two harness attachment types, backpack and leg-loop, following the design and attachment procedures described in Scarpignato and Stanley et al. (2026). Both harnesses designs were constructed of 1.0mm Stretch magic and secured with two (leg-loop) or three (backpack) 1.0mm crimps. After a one-month trial period, we found that backpack harnesses were more likely to remain attached, with no observed impacts and the harness material remaining intact.*

Platforms for Reporting

- Online supplementary information
- Online repositories (e.g., Movebank, Motus Database, Dryad)
    - Example: Movebank Deployment Attributes; Attachment Comments

Methodological Information

What to Report

- Attachment reference
- Harness material and size
- Securing material and size
- Device plus harness weight (recommended < 3-5% of body weight; Kenward 2000)
    - If possible, include raw data on bird body mass to assess experimental load
- Fitting method
- Reason attachment method chosen
- Reason harness and securing material type and size chosen
- Total handling time (processing and device attachment)
- Example: *To capture movement for one full-annual cycle, we attached [manufacturer] barometric pressure geolocators (0.5g; device + harness mass = 0.8g, <3% body weight) with a leg-loop harness (Scarpignato and Stanley et al. 2026) made of 0.8mm Stretch magic and two 1.0mm crimps following the fitting method as described in Scarpignato and Stanley et al. (2026). Leg-loop harnesses made with Stretch magic have been used on similar species [add appropriate references] but to check for impacts of the harness methodology, we monitored return rates and evaluated physical condition of tagged and a sample of un-tagged birds in the same population.*

Platforms for Reporting

- Methods Section or Online Supplementary Information
- Online repositories (e.g., Movebank, Motus Database, Dryad)
    - Example: Movebank Deployment Attributes; Attachment body part, Attachment type, Device Mass Total, Other comments section

Box 1: Continued

Results: Outcomes and Impacts

What to Report

- Positive, negative, or no impacts, and if possible, reason of harness success and failure
    - If unable to report impacts or indeterminable indicate this in your study. Example: *Because this species exhibits low site fidelity and few individuals are expected to return to this breeding site, evaluating return rates or potential impacts through recapture was not feasible.*
    - If possible, include information about the mechanism driving impacts from the attachment method. Example: *We observed a 1-mm abrasion under the wing of one of five recaptured birds. The abrasion was noted after harness removal, however, because only one individual was affected, we consider the fit too tight rather than abrasive material to be the likely cause.*
        - Possible impacts to report from attachment method include but are not limited to: abrasion, loss of feathers, callus formation, flight impairment, immobilization, entanglement, strangulation, death
    - Injury scores, similar to what has been developed for interventions in other taxa (see Soulsbury et al. 2019)
- Return rate (the ratio of resighted individuals, with and without a device, to the total number marked) and/or recovery rate of devices. While monitoring return rates may not reveal specific causes of impacts, it can help assess potential effects and detect patterns of positive or negative outcomes.

Platforms for Reporting

- Results Section or Online Supplementary Materials
- Online repositories (e.g., Movebank)
    - Example: Movebank Attributes; Fate
        - We encourage researchers to fill out all relevant attributes
- Community-based forums (e.g., Ornithology Exchange, WILDLABS)
- Permitting offices
    - The BBL will send out memos to relevant banders if alerted about a negative impact from a particular attachment method.

Preparation and Training

- Literature review
- Consult other resources such as, Guidelines for the Use of Wild Birds in Research (Fair et al. 2023), The North American banders' study guide (North American Banding Council 2001), or species survival or recovery plans
- Contact permitting offices to get information about species or similar species
- Reach out to species workings groups
- Review online repositories to contact data holders (see Box 1 in Scarpignato et al. 2023)

suitability of certain elements of the attachment method. Online repositories could again serve an important role in collecting and standardizing the information presented. Community-based forums (e.g., Ornithology Exchange, WILDLABS) could also provide an avenue for researchers to share their experiences with attachment methods. Second, due to the difficulty in distinguishing harness effects from more general device effects (e.g., mass of device) or other factors, it is essential that experiments be designed explicitly to monitor and report on harness effects (i.e., controlled experiments, Casper 2009). We encourage researchers to use pilot studies, in the wild (e.g., Bedrosian and Craighead 2007, Clewley et al. 2021a) or in captivity (e.g., Herrod et al. 2014, Longarini et al. 2023), when possible, and encourage editors to publish such studies even when sample sizes may be low, or the study is descriptive. Additionally, if possible, we urge the bio-logging community to incorporate the monitoring and reporting of return rates of birds carrying bio-loggers (ideally with a control; see Macey et al. 2025) and any impacts encountered (i.e., neutral, negative, or indeterminable) as standard practice (Box 1), regardless of the goal of the study or the sample size achieved. While monitoring return rates may not reveal specific causes of impacts, it can help assess potential effects and detect patterns of negative outcomes. Refinement of attachment methods will often occur only once a concern has been identified. Therefore, the development of studies to test attachment methods, standardized reporting of methods, and improved monitoring of impacts (with or without controls) are all needed to allow for the refinement of methods for better research and animal outcomes.

Attachment Protocols

Detailed attachment protocols or SOPs are often excluded from the peer-reviewed literature, making it challenging for researchers to replicate or adapt existing methods. Instead, protocols and considerations in choosing harness designs and materials are typically found in less accessible formats, such as white papers, internal protocols, and informal knowledge passed down from other researchers or shared through personal communication channels (Anderson et al. 2020, Mackenzie et al. 2020 but see Clewley et al. 2021b). Limited accessibility creates barriers to training, standardization, and innovation, as these protocols may be unavailable to the broader bio-logging community (Bodey et al. 2018). For instance, a report by researchers working with vultures found that adjustments to protocols are common (Anderson et al. 2020), yet there is often no formal venue for publishing such modifications. To address this issue, we encourage reviewers and editors to require researchers to include more detailed methodological information and, when relevant, comprehensive protocols. These could be published as online supplementary materials or in data repositories (e.g., Dryad, Open Science Framework), similar to how primary data and computer code are often required for study replication. Additionally, professional societies (e.g., ornithological societies, banding councils), permitting offices or online repositories could serve as platforms for these records. In the United States, information on attachment methods that have been successfully used on species can be obtained from the BBL. Ensuring broader access to attachment protocols would facilitate proper training, promote standardization, and create a more equitable global research environment.

To aid in this endeavor, we provide a detailed and illustrated device attachment protocol in both English and Spanish for backpack and leg-loop harness attachment (Supplementary Material 2–5) with the intention of making it widely accessible and to offer: (1) a starting point and reference for trained and permitted researchers who are new to the field, (2) a generic protocol that can be built upon by others and tailored to specific species or environmental conditions, and (3) an example of the type of detailed information that would be useful to include to facilitate replication or modification of methods. We designed the protocol to standardize and clarify the procedure of harness attachment, ensuring consistency, reproducibility, and animal welfare across studies. However, given the diversity of species, environmental conditions, and study objectives, we emphasize that our protocol is not intended to be a one-size-fits-all method and additional materials or considerations may be necessary. Sharing protocols and considerations when selecting an attachment method enables key information to be refined and adapted to different species, rather than simply transferred without modification (Bodey et al. 2018). As such, we encourage others to test and refine the protocol for specific species and study needs and, importantly, publish the results of their successful or unsuccessful modifications.

Study Limitations

Our review resulted in key insights and recommendations that will improve knowledge transfer and methodological improvements of attachment methods for tracking birds. However, some caveats should also be considered when interpreting our findings. First, as stressed throughout this manuscript, it can be difficult to disentangle the impacts of the attachment method from those of the device or rely on author descriptions of impacts without an experimental approach. Our primary goal was not to directly assess impacts, but instead to emphasize the importance of reporting whether impacts are present, absent, or cannot be assessed, as a critical step toward identifying potential elements of concern and evaluating patterns of positive and negative outcomes. It is also important to acknowledge the potential for reporting bias across our two approaches, where the published literature may favor reporting neutral impacts whereas the survey may be more likely to emphasize negative impacts (Hill and Elphick 2011). This consideration further reinforces the value of the survey and the need for future replication to understand all device attachment outcomes. Secondly, the exclusion of non-English studies and advertisement of the survey exclusively in English almost certainly limited participation and the inclusion of relevant data from non-English speaking researchers or journals. Much bio-logging research occurs outside of English-speaking regions and translating and advertising the survey in multiple languages, as well as on global platforms could help broaden participation across a larger community of researchers. Finally, to understand true impacts of tag attachment without fear of repercussion, we chose to conduct an anonymous survey and did not collect information on the previous experience of survey respondents. Likewise, we do not have comparable data on the experience of researchers in the literature review. Nonetheless, many survey respondents provided information for more than one taxonomic order (36%) or attachment design (65%), which serves as a potential indicator of experience (see Supplementary Material 1 Appendix 1). However, we cannot rule out that the higher reporting of impacts in the survey could be attributable to a portion of respondents having less experience deploying transmitters on birds. The survey results indicate that a wealth of information about device attachment is available from the ornithological community, and we recommend future anonymous surveys include non-identifying questions to help gauge respondents' background and experience.

Conclusion

Bio-logging is a rapidly growing field with great potential to obtain valuable information to inform biology and conservation, but the challenge of standardized reporting remains unmet. While we are not the first to advocate for this need (Lameris and Kleyheeg 2017, Bodey et al. 2018, Geen et al. 2019), we urge the bio-logging community to share their findings and methodological improvements through publication, making best practices more accessible. In this regard, we offer recommendations on the key methodological details for device attachment that should be included in publications, as well as suggestions on where to report methodologies and impacts (Box 1). We also provide detailed and illustrated protocols we developed for two common harness attachment techniques in English and Spanish (backpack and leg-loop harnesses; Supplementary Material 2–5). Although these are near-term solutions, we see the potential to develop more formalized guidelines for device attachments and assessments of harness impacts on birds (e.g., impact scores), along with encouraging experimental studies in the wild or in captivity before broader deployments to ensure robust evaluation of techniques. Institutions (e.g., ornithological societies, permitting offices, banding councils) have long played a leading role in the development of guidelines and trainings for researchers and institutional animal care committee. We also encourage these groups to specifically emphasize the importance of device attachment methods and reporting. The collaborative effort to standardize and disseminate protocols, monitor impacts, and refine techniques will help assess the success and applicability of different attachment methods across taxa and improve data quality and outcomes for birds. Similar to the effort to promote ethical and effective methods for laboratory animals (3Rs; Zemanova 2020, Soulsbury et al. 2020), we hope these efforts can spur similar efforts in the bio-logging community and ensure that bio-logging continues to be a powerful, safe tool for understanding and conserving birds.

Supplementary material

Supplementary materials are available at *Ornithology* online, including detailed and illustrated protocols for backpack and leg-loop harnesses in English and Spanish (Supplementary Material documents 2-5) and an evaluation of reported outcomes for both harnesses from our literature review and survey (Supplementary Material documents 1).

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Ethics statement

This anonymous survey did not require IRB approval under institutional guidelines.

Conflict of interest statement

The authors declare no conflicts of interest.

Author contributions

Conceptualization and Methodology—A.L.S., C.Q.S., P.P.M.; Data collection—A.L.S., C.Q.S., A.M.A., N.W.C., A.-L.H., V.H., F.G.L., M.E.R.; Data analysis—A.L.S., C.Q.S.; Writing—original draft—A.L.S., C.Q.S.; Writing—review & editing—A.L.S., C.Q.S., A.M.A., N.W.C., K.M.D., A.-L.H., V.H., F.G.L., M.E.R., P.P.M.; Project administration—A.L.S., C.Q.S.; Funding acquisition—P.P.M., A.-L.H.

Data availability

The selection of papers and raw data from our literature review and backpack and leg-loop harness survey results are available at Scarpignato and Stanley et al. (2026).

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