Minimum reporting standards to promote animal welfare and data quality in biologging research

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Abstract

1. Over the last six decades, the biologging research community has reduced instrument impacts on study animals by miniaturizing devices, employing sophisticated release mechanisms, and developing other novel technological advancements. However, biologging devices can still impact animal physiology, behavior, and demography - the very biological metrics the instruments are meant to measure. Recent meta-analyses have emphasized the subjectivity of field-wide “rules of thumb” such as the 3% rule, but opportunities to quantify impacts more objectively can be expensive or impossible to implement when instrumenting new species. There is therefore a time-sensitive need for systematic reporting of biologging instrument characteristics based on known impacts to animal welfare and data quality.
2. We comprehensively reviewed 175 biologging impact studies from the last 25 years to draw broad, multispecies connections between instrument characteristics and animal physiology, behavior, and/or demography. We build on impact studies that focus on a single species, instrument type, or attachment

method to offer solutions applicable across those taxa, technologies, and methodologies.

3. From our review, we distilled eight best practices for biologging researchers with a particular focus on minimum reporting standards as a low-cost, high-impact way to promote animal welfare and data quality. We propose a minimum reporting standard, informed by our review and presented as a machine-readable checklist, that biologging researchers can include with their manuscripts or data submissions to provide data for future meta-analyses. We also present an example of a completed checklist to demonstrate the feasibility of such a standard.
4. Robust biologging infrastructure, beginning with a minimum reporting standard informed by the literature on instrument impacts, will facilitate the expansion of biologging across the globe and across disciplines while preserving animal partnerships and improving data quality. As biologging instruments become less expensive and more accessible, researchers, journals, and funders are better positioned than ever to broaden and implement these standards.

1. Introduction

Discoveries in ecology, physiology, and animal behavior increasingly come from instrumented animals that collect *in-situ* environmental and biological data (Beltran et al., 2024; Costa et al., 2012; Kays et al., 2015; Ropert-Coudert & Wilson, 2005; Wilmers et al., 2015). Modern instruments can be small enough to attach to insects (Kissling et al., 2014) or implant in goldfish (Lee et al., 2019), cheap enough for large sample sizes (Sequeira et al., 2019), and sophisticated enough to concurrently measure animal decisions and environmental conditions (Wild et al., 2023). This “golden age” of biologging has allowed us to collect ecological data at an entirely new scale (Davidson et al., 2020; Wilmers et al., 2015), growing from individuals in a single location at a specific time of year to ecosystem-wide monitoring across seasons and continents (Hindell et al., 2020). As biologgers inform both basic and applied science across disciplines, many researchers are seeking guidelines for best practices of similar breadth.

Biologging best practices have been discussed since the field’s inception more than six decades ago (Casper, 2009; Godfrey & Bryant, 2003b; Hays et al., 2016; Kooyman, 1965; Putman, 1995; Vandenabeele et al., 2011). Since then, technological advances have occurred more rapidly than researchers and regulatory bodies can adjust their standards, resulting in arbitrary “rules of thumb”. The “3% rule”, for example, suggests that instruments should weigh less than 3% of the study animal’s body mass (Phillips et al., 2003). However, several recent studies have emphasized the subjective nature of the rule (Barron et al., 2010; Bodey et al., 2018; Lear et al., 2018; Vandenabeele et al., 2012). Additionally, while the miniaturization of biologgers has resulted in smaller instruments, these smaller devices have been deployed on increasingly smaller animals (Portugal & White, 2018), necessitating further conversations about and solutions to minimize instrument impacts.

Novel, fundable, impactful science often demands larger sample sizes, increased sampling across demographic groups, smaller study species, longer study durations, and more data streams, all of which require more from the animals that carry biologging instruments. However, the acceleration of biologging science has far outpaced the development of reporting guidelines, which has hindered our ability to understand the impacts of devices on the animals that carry them. As biologging efforts grow, ad-hoc reporting of instrument impacts will be insufficient to ensure animal welfare and scientific rigor (McMahon et al., 2012; Rutz, 2022). The biggest challenge in realizing these best practices is not technological ability or concern for the animals, but rather the lack of agreed-upon guidelines for documentation, such as a minimum reporting standard. Minimum reporting standards for data, often presented as a table or checklist, are common in other scientific disciplines to promote data transparency, reproducibility, and utility (Chen et al., 2022; Field et al., 2008; Rund et al., 2019; Taylor et al., 2008). Biologging researchers have called for minimum reporting standards in the past, particularly for instruments that record animal location (Campbell et al., 2016; Casper, 2009; Lennox et al., 2017; Rutz, 2022; Sequeira et al., 2021a; Williams et al., 2020). As biologging instruments become less expensive and more accessible, there is an increasing need for researchers, journals, and funders to broaden and implement these standards.

We comprehensively reviewed 200 biologging impact studies from the last 25 years to draw broad, multispecies connections between instrument characteristics and impacts on animal physiology, behavior, and/or demography. We build on impact studies that focus on a single species, instrument type, or attachment method to offer solutions applicable across those taxa, technologies, and methodologies. We summarize the results of this literature review, with particular emphasis on the role of meta-analyses in identifying impacts that were otherwise impossible to distinguish. Based on the findings of the review, we then propose best practices for biologging researchers across all stages of a biologging study, from development to deployment to reporting. We identify minimum reporting standards as a prime opportunity for a low-risk, inexpensive, and impactful intervention, and we draw on our literature review to propose a minimum reporting standard that biologging researchers can use in their work. Finally, we offer an example of how the minimum reporting standard might be used in practice.

2. Review of impacts: considerations across disciplines and taxa

Understanding previous impact studies is one of the most informative tools for designing and deploying biologging instruments. While many impact studies exist, they are almost always taxa- or method-specific. Here, we synthesize more than 175 recent empirical biologging impact studies to generalize across transport modalities (walking, swimming, and flying) and research disciplines (physiology, behavior, and demography). Initial papers were queried from Google Scholar and Web of Science using keywords “biologg*” and “impacts”. Relevant studies published between 1995–2025 were identified using backwards and forwards citation tracing. While the review process was not systematic, it enabled us to efficiently capture broad patterns in biologging research across the last quarter century. The review and synthesis directly informed the development of broadly applicable best practices, detailed in section 3 and Figure 1, as well as a detailed checklist to be used by future biologging researchers (See section 4 and Table 1). Details of over 170 individual studies are available in the Supplemental material (Table S2).

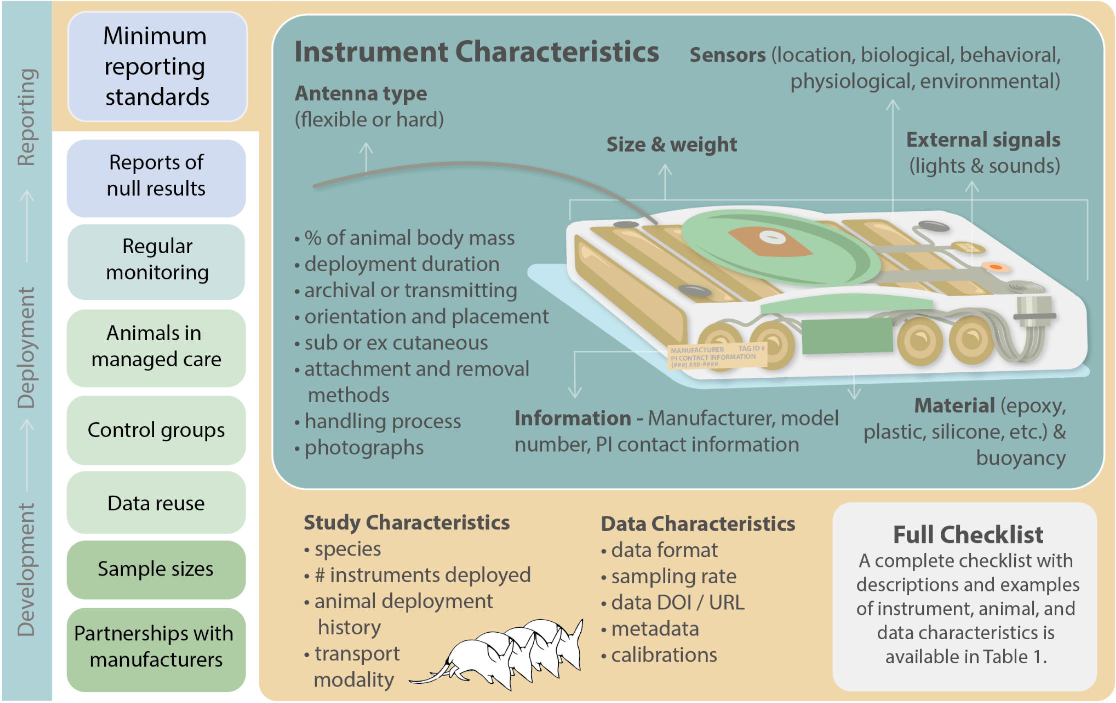

Figure 1. Recommendations for best practices during development, deployment, and reporting processes of biologging science, including detailed minimum reporting standards for instrument, study, and data characteristics. Sample instrument characteristics that would be useful to document and report with biologging manuscripts include size, mass, sensors, orientation, material, cross-sectional shape, and attachment/detachment method. For details and examples for all characteristics, see Table 1.

Instruments may impact the animals that carry them across multiple disciplines, including physiology, behavior, and demography (Table 2). These effects are largely influenced by the interaction of instrument type and method of attachment with the animal's transport modality. In a hypothetical example, a tail-mounted GPS tag (*instrument attachment/type*) attached to a swimming + flying bird (*transport modality*) may increase the metabolic costs of flight (*physiological impact*), which is associated with shorter foraging trips (*behavioral impact*) but does not affect chick growth rates (*lack of demographic impact*). It is important to note that while demography may not be affected in this example, physiological or behavioral adjustments may nonetheless compromise the "natural" data collected by the instruments. Due to resource and logistical limitations, most studies can only feasibly report impacts for one discipline, if impacts can be quantified at all. The relative importance of impacts and availability of solutions varies widely within and across transport modalities and taxa, particularly for species that use multiple transport modalities (Figure 2). Transport modalities, instrument and attachment types, and other relevant terms are defined in the Glossary.

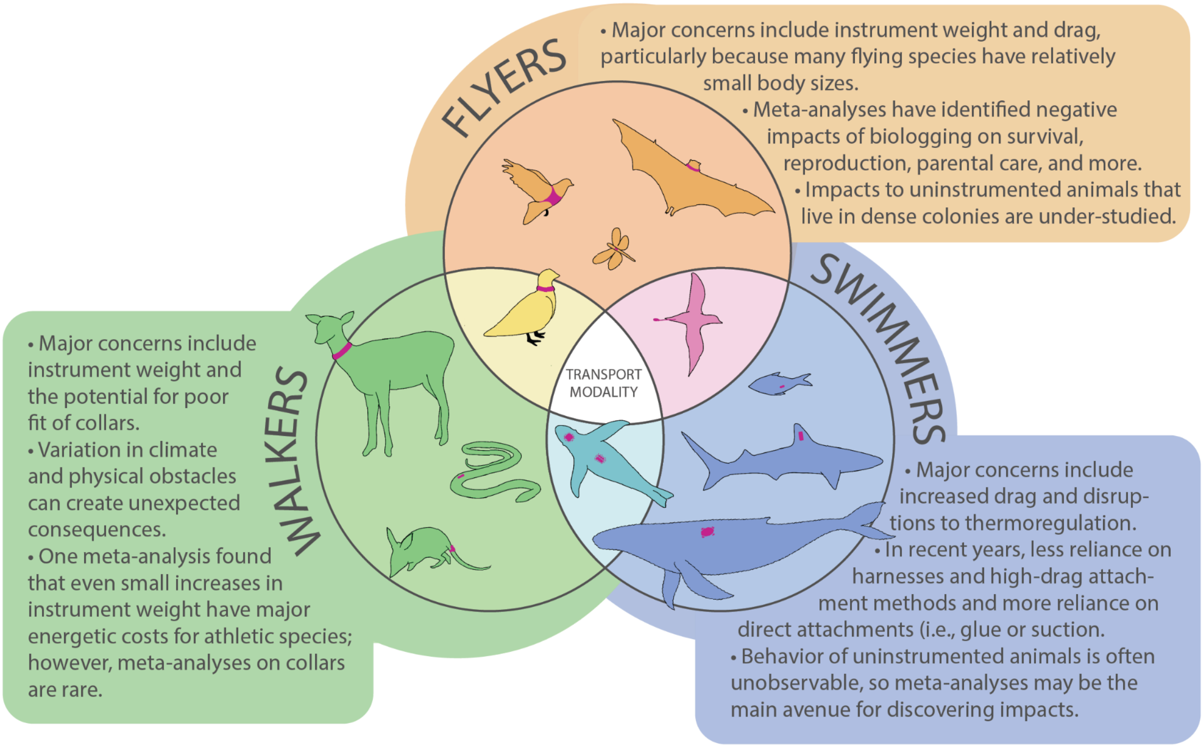

Figure 2. Typical instrument attachment methods and a summary of their associated impacts across walkers, swimmers, and flyers. Animals that use multiple transport modalities face concerns associated with each modality. We highlight the importance of meta-analyses for uncovering impacts to animal welfare or data quality across flyers, walkers, and swimmers.

2a. Impacts to Walkers.

Terrestrial environments host a wide range of walking specialists that must contend with high environmental heterogeneity, climate variability, and physical obstacles. The instruments most frequently affixed to walking specialists are biologging collars such as GPS collars, which can cause injuries to the animal’s neck due to chafing if not fitted properly (Hopkins & Milton, 2016; Juarez et al., 2011; Schoenecker et al., 2020). Collars must be sized appropriately to minimize interactions with the environment during movement and growth and prevent debris, such as twigs, from becoming lodged in the collars (Juarez et al., 2011). Ear tags and expanding collars are a helpful tool for avoiding injuries when instrumenting juvenile walkers without disrupting their growth (Donadio et al., 2012; Santos et al., 2021).

In addition to heterogeneity in physical features, terrestrial environments also have variable climates, and changes in precipitation or temperature can alter the impacts of biologging devices on the animals that carry them. For example, in heavy-rainfall areas, the tape used to attach instruments to the tails of greater bilbies (*Macrotis lagotis*) occasionally became saturated and compacted with mud, causing skin injuries (Cornelsen et al., 2022). For walking ectotherms, healing rates are affected by temperature-dependent metabolic rates, which can disrupt recovery from surgery or other instrument-derived injuries (Alworth et al., 2011). Physiological impacts to walkers are often attributed to disruption of fur or feathers, leading to compromised thermoregulation and therefore elevated energy expenditure (Godfrey & Bryant, 2003a) or reduced body condition (Robstad et al., 2021).

Impacts to walking species are often assessed at the scale of behavior, and several studies have found significant behavioral changes among instrumented walking specialists. For example, a GPS collar weighing 1.8 kg reduced walking speed of zebras (*Equus burchelli*) while foraging by >50% relative to a collar weighing 1.2 kg (Brooks et al., 2008). Both collars weighed substantially less than 3% of the animal’s body mass, acceptable under the traditional “rule of thumb.” These results raise concerns not only about impacts to animal well-being, but also data quality. Additionally, the attachment methods and instrument placement appropriate for a slow-moving herbivore are very different from those appropriate for a high-speed carnivore. Instruments, especially GPS collars that are not flush with the skin, can affect the acceleration of athletic animals that rely on running speed to catch prey or escape predation (Wilson et al., 2021). In some athletic walking species, the forces exerted by instruments weighing less than 3% of the animal’s body weight created much larger inertial forces when the animal was moving at speed (Wilson et al., 2021). For the fastest species, carrying these small instruments at top speeds was the equivalent of carrying a device weighing up to 19% of the animal’s body mass (Wilson et al., 2021).

These findings informed our decision to include detailed instrument and animal characteristics in our minimum reporting checklist, including instrument dimensions and weight in air (Figure 1, Table 1). The behavioral impacts of biologgers on extremely athletic walking specialists is an important data gap, particularly for taxa that rely on behaviors close to their physiological limits.

In summary, researchers instrumenting walking species often must consider environmental heterogeneity, climate variability, and physical obstacles. When possible, continuous monitoring is helpful for assessing whether these factors will negatively impact the animals and the data. Additionally, despite the unique constraints associated with biologging collars, there appear to be relatively few meta-analyses available to address their impacts. A minimum reporting standard for animal, data, and instrument characteristics would help to fill this knowledge gap.

2b. Impacts to Swimmers.

In high-drag aquatic environments, minimizing mass and maximizing streamlining are both important to reduce instrumentation impacts (Zhang et al., 2020). Researchers instrumenting aquatic species employ a diversity of attachment methods, including suction cups for cetaceans, glue for pinnipeds, tape for seabirds, subdermal attachment for turtles and sharks, and implants for fish. Some attachment methods, particularly harnesses and collars, have negatively impacted animal survival in the past (Culik & Wilson, 1991). Because the impacts of these methods were published, the field has largely been able to move towards lower-impact methods (Agnew et al., 2013; Best et al., 2015; Gauthier–Clerc et al., 2004; Hamelin & James, 2018; McMahon et al., 2008).

The physiological impacts of instrumentation on swimmers include changes in energy budgets, thermoregulatory processes, and body condition. Endothermic aquatic species often rely on blubber, fur, or feathers for insulation in a thermally conductive environment (Favilla & Costa, 2020). Biologging instruments can exacerbate thermoregulatory requirements by disrupting their insulation (Nankey et al., 2021).

Instrumentation may impact species that rely on fur or feathers (Gillies et al., 2020; Robstad et al., 2021) more than species that rely on blubber or other thermoregulatory adaptations (Agnew et al., 2013; Berman & Quinn, 1991; McCafferty et al., 2007; McMahon et al., 2008). For example, cutting fur to remove glued instruments from northern fur seals (*Callorhinus ursinus*) significantly decreased the thermal resistance in the area around the cut fur; however, utilizing a neoprene patch for attachment mitigated the negative thermoregulatory effects (Nankey et al., 2021). The potential for thermoregulatory impacts is one reason we included attachment method and location in the minimum reporting standard for instrument characteristics (Figure 1, Table 1).

Injuries from instrument attachments on swimming animals are usually minor. Glued and suction-attached devices may cause minor irritation, but significant injuries are rare. Subdermal attachments, such as instruments attached by screws to a shark's dorsal fin, can cause permanent cosmetic damage; however, the damage does not seem to impact growth or survival (Jewell et al., 2011). Attachment injuries may be relatively infrequent in swimmers because instruments are often placed flush to the skin to reduce drag, reducing opportunities for chafing, fouling, and entanglement.

Biologging can allow for otherwise challenging underwater behavioral observations (Marshall, 1998), but control data are needed to ensure that instruments capture normal animal behavior. Biologging devices attached externally to swimmers increase drag forces, which can increase metabolic rate (Rosen et al., 2018), cost of transport (Tudorache et al., 2014), and power consumption (Vandenabeele et al., 2015). Some swimmers change their behavior to compensate for physiological impacts, such as reducing swim speed to compensate for increased locomotor costs (Van Der Hoop et al., 2014). Compensation may even happen across individuals, as in cases where un-instrumented parents increase offspring provisioning to compensate for an instrumented partner's reduced contributions (Symons & Diamond, 2019). The potential impacts of drag are frequently studied in collaboration with researchers who can facilitate impact studies through captive animal trials and/or computer modeling, both of which are excellent options to explore prior to instrumentation on wild animals. The instrument characteristics that are most likely to contribute to drag include attachment method (i.e., harness vs. glue) and cross-sectional shape (streamlined vs. complex) (Balmer et al., 2014; Fossette et al., 2008; Kay et al., 2019; Shorter et al., 2014; Zhang et al., 2020). While attachment methods are frequently reported in manuscripts, cross-sectional areas are not, likely because they can be difficult to calculate. We nonetheless recommend estimating cross-sectional areas whenever possible, particularly for swimming species.

A swimmer's buoyancy may change as they dive, become pregnant, or gain/lose weight over the course of a migration (Adachi et al., 2017). Instrumentation can affect buoyancy, resulting in behavioral and physiological changes (Bouyoucos et al., 2017; Lear et al., 2018). For example, northern elephant seals (*Mirounga angustirostris*) carrying experimental buoyancy blocks adjusted their swimming stroke rate to maintain their swim speed (Aoki et al., 2011). Biologging devices—intended to record non-biased physiological or behavioral data—should be neutrally buoyant when possible, particularly for long deployments. We therefore included buoyancy as a part of the instrument characteristics reporting standard for biologging studies involving swimmers (Figure 1, Table 1).

The potential for biologging instruments to increase predation risk via reduced mobility or signal production has been hypothesized, but is thus far unsubstantiated. However, there is evidence that telemetry instruments, such as acoustic transmitters, have a "dinner bell" effect for potential predators (Rub & Sandford, 2020). Many biologging instruments produce signals such as light or sound that may attract predators. For example, predation rates on instrumented eels (*Anguilla rostrata*) were extremely high (75%), but it is unclear whether these mortality rates were higher than un-instrumented counterparts (Béguer-Pon et al., 2012). Sharks in particular forage by detecting the weak electromagnetic fields of their prey (Kalmijn, 1971) and have been known to ingest instrumented prey (Kerstetter et al., 2004). Nonetheless, it remains an open question if carrying electronic instruments significantly increases the risk of mortality for swimming prey species. Including signal production in the minimum instrument characteristics reporting standard could help answer this question in the future.

In summary, researchers instrumenting swimming animals must consider several unique constraints, including the increased drag, density, and heat capacity of water. Because it is rare to validate swimmers' biologging data with visual observation, robust reporting of instrument characteristics and resulting meta-analyses may be the main avenue for discovering impacts to animals and data quality.

2c. Impacts to Flyers.

Instrumented flyers, including bats, birds, and insects, typically have smaller body sizes than walkers or swimmers and are often instrumented with backpack harnesses, rings, implants, or trailing attachments (Kays et al., 2015; Ropert-Coudert & Wilson, 2005; Soulsbury et al., 2020). Bats and walking birds such as grouse are frequently collared. For very small animals such as insects, miniature instruments are usually glued to the animal's back. While there is a rich literature associated with the impacts of instrumentation on birds, the impacts to other flyers, especially invertebrates, are less well known (Batsleer et al., 2020; Soulsbury et al., 2020). Major meta-analyses of avian species have been possible in large part due to the reporting of instrument characteristics such as weight in avian biologging manuscripts, which is less common in other taxa.

Powered flight carries the highest metabolic demands of any locomotor mode (Alexander, 2002). When instrumentation adds to these already considerable costs, there can be substantial impacts to daily energy expenditure and mass balance (Barron et al., 2010; Evans et al., 2020; Mizrahy-Rewald et al., 2023; Pennycuick et al., 2012; Portugal & White, 2022; Vandenabeele et al., 2012, 2014). For example, instrumented homing pigeons lost an amount of body mass equivalent to the mass of the instrument they carried (Portugal & White, 2022). The recommended limit for instrument mass is

3% of the animal’s body mass; however, physiological impacts have been documented for smaller instruments as well (Barron et al., 2010).

Although instrumentation best practices for avian flyers are well-established, instrumentation can nonetheless result in unexpected injuries. For example, heat from instruments attached to the upper backs of ibises (*Geronticus eremita*) caused corneal opacity because of the birds’ roosting posture (Fritz et al., 2020). In this case, careful monitoring during the study and a small shift in attachment location prevented damage in subsequent deployments. Instrument implantation carries additional risks because it requires a surgical procedure. However, once implanted, these instruments often cause fewer negative impacts than external devices (White et al., 2012). External tags on flyers share swimmers’ difficulties regarding drag (Bowlin et al., 2010), and collared flyers (typically bats) face the same issues with chafing and entanglement as collared walkers (O’Mara et al., 2014).

The potential for negative physiological impacts can increase with the duration of instrument deployment. Instrumented murre species (*Uria aalge* and *Uria lomvia*), had higher levels of corticosterone after year-long instrument deployments, while short-term deployments had no effect on corticosterone levels (Elliott et al., 2012). Researchers should consider and report the deployment duration when designing a study, particularly if the deployment period will overlap with multiple major life events such as breeding, molting, or migrating (Figure 1, Table 1).

Some flying animals change their behavior to compensate for physiological or demographic impacts. Instruments can reduce the amount of time spent flying (Chivers et al., 2016; Hagen et al., 2011), reduce flight speeds (Tomotani et al., 2019), and disrupt offspring provisioning behaviors (Evans et al., 2020; Paredes et al., 2005). Additionally, many of the most commonly instrumented flying specialists undergo long migrations and carry their instruments across entire oceans or continents (Kissling et al., 2014; Pennycuick et al., 2012; Shaffer et al., 2006). Instrument weight and shape, among other characteristics, are critical to report, as they could cause changes in flight behavior, migration distances, and survival. Attachment is also important: backpack attachments have been shown to alter flying behavior more than leg loop attachments, likely because of increased drag (Longarini et al., 2023). Behavioral adjustments may allow species to compensate for instrumentation without altering reproductive behaviors such as chick provisioning (Gillies et al., 2020; Sergio et al., 2015). Further study is necessary to determine when changes in behavior (or lack of compensatory behavior) may cascade to demographic impacts.

A review of more than 200 studies on instrumented birds found negative effects of instrumentation on survival, reproduction, and parental care (Bodey et al., 2018). Intergenerational and partner-specific effects of device attachment have also been noted in multiple flying species (Evans et al., 2020; Paredes et al., 2005). Seabirds, for example, are often monogamous, share parental investment, and live in large colonies where instrumentation can affect both the instrumented individual, un-instrumented co-parents, and offspring (Chivers et al., 2016; Hooijmeijer et al., 2014; Paredes et al., 2005). Un-instrumented partners, though not burdened with a physical weight, must compensate for their partner's behavioral changes to buffer effects on offspring (Evans et al., 2020; Paredes et al., 2005). Elevated parental investment has been linked to the potential for reduced survival in many bird species, indicating potential downstream consequences for instrumentation (Reid, 1987; Santos & Nakagawa, 2012). Whether or not instruments increase parental investment and affect conspecific partners is an important data gap for non-avian flyers, especially when they exhibit colonial or monogamous behavior, like some bat species. With many global populations of birds, bats, and insects at the highest levels of extinction risk (Cardoso et al., 2020; Şekercioğlu et al., 2004), it is imperative to understand and minimiz the impacts of devices on demography.

2d. Summary: complexity of instrument impacts

Across the studies synthesized here, biologging instruments are shown to have many potential impacts across disciplines and time scales. It is difficult to compare these impacts to each other in the same species, let alone across species from different transport modalities (Figure 3). Additionally, instrumentation may be more disruptive in certain seasons, particularly during seasonal periods of mass change such as migration or molt (Mazzaro & Dunn, 2009; Portugal & White, 2022; Schoenecker et al., 2020). Interannual variation in environmental and ecological conditions may result in differential device impacts across years of high and low productivity, even when instrument characteristics remain the same (Speakman et al., 2020). The interpretation of impacts is widely variable; a similar impact over a comparable time scale may be considered severe by one study and minor by another (S. P. Vandenabeele et al., 2012). Intraspecific variation can make impacts even less clear, particularly in studies without control groups or large sample sizes (Robstad et al., 2021). Device deployments on species that share many traits—including their use of multiple transport modalities—have produced contrary results (Agnew et al., 2013; Gauthier–Clerc et al., 2004; Ropert-Coudert & Wilson, 2005; Symons & Diamond, 2019), illustrating the need for robust reporting even in well-studied systems.

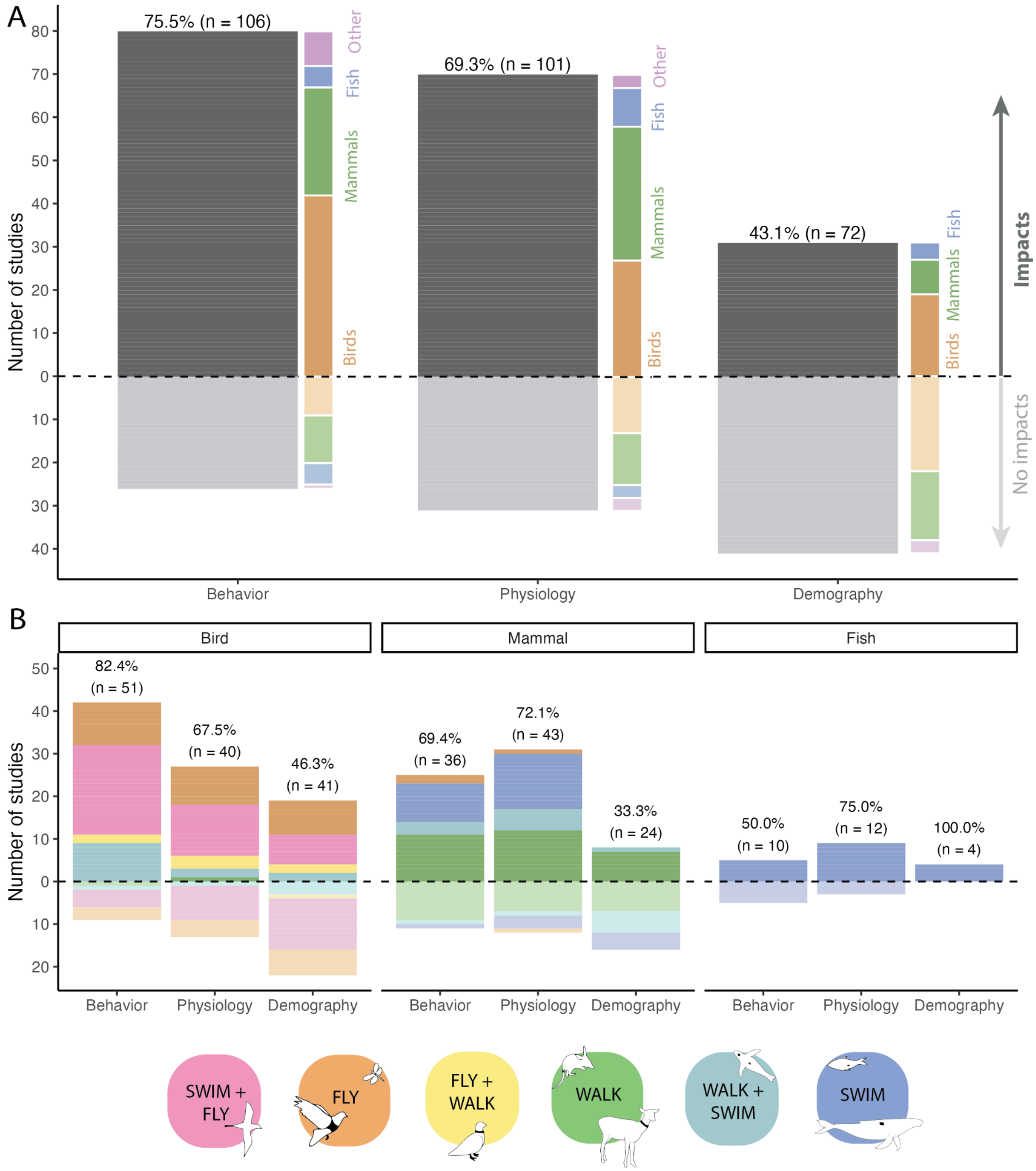

Figure 3. A: Studies from a comprehensive review of biologging studies that quantify the presence (above the horizontal line, y = 0) or absence (below horizontal line) of impacts on behavior, physiology, and demography (n = 176). Bars above the dashed line indicate studies that found impacts of instrumentation; bars below the dashed line indicate studies that did not find an impact. Studies are also broken down by broad

taxonomic group. Percentages refer to the number of studies that found impacts out of n studies in that category and for that taxa. All impacts, even minor ones, are considered as a "Yes" due to the subjectivity of such characterizations. Some studies appear multiple times (i.e, the same study may find impacts in multiple disciplines, or may find impacts in some disciplines but not in others). We focused on papers published in the last twenty-five years due to major differences in best practices prior to the last few decades of biologging research. A detailed bibliographic database of all papers represented in this figure is available in Table S1, containing information about species, attachment type, and specific instrument impacts. B: Number of studies on instrument impacts across three major groups: birds, mammals, and fish. Each category is color-coded by transport modality. Reptiles, insects, and mollusks are also included in panel A as category "Other", but were excluded from visualization in panel B.

Approximately 16% of the studies we reviewed looked at more than one species, and 6% looked at five or more species. Ninety percent of multi-species studies reported impacts, compared to 73% of studies overall. Of all studies that reported impacts, few explicitly described sample size selection, control groups, pilot studies, impact monitoring strategies, instrument characteristics, or open data strategies. This information, not typically included in the manuscript text or supplementary data in biologging studies, would allow researchers to continue building on the existing foundation of biologging knowledge. Efforts to bring this information into the published literature through minimum reporting standards could facilitate major breakthroughs in future scientific endeavors.

3. Recommendations for biologging best practices

From our comprehensive, multispecies review of instrument impacts, we distilled eight best practices for biologging researchers, spanning the process of instrument development, deployment, and reporting (Figure 1). We focus in particular on minimum reporting standards as a low-cost, high-impact way to promote animal welfare and data quality (detailed below and in Table 1).

3a. Establish partnerships during the design phase.

Partnerships between instrument manufacturers and researchers can facilitate the development of low-impact instruments (Williams et al., 2020). Researchers can provide expertise on which characteristics are important in their study system (e.g., hydrodynamic shape, species-specific attachment, battery size, remote release, etc). Instrument manufacturers can use their engineering and design expertise to make feasible adjustments. Researchers and engineers can use computational modeling to test new sensors (Goldbogen et al., 2017), calculate impacts (Jones et al., 2013), and optimize designs and positions (Jones et al., 2013; Kay et al., 2019).

3b. Carefully choose sample sizes.

Selecting a sample size is a crucial part of biologging study planning (Gutowsky et al., 2015; Sequeira et al., 2019). While some experimental biologging studies are limited in sample size due to the expense of instruments, researchers using off-the-shelf instruments may be able to reduce their sample sizes depending on the scale of their ecological question. Ensuring appropriately small sample sizes conserves resources and reduces the number of individuals that may experience negative impacts from instruments (Hays et al., 2016; Linssen et al., 2024).

3c. Minimize deployments by using existing data where possible.

After defining the research question, required sample size, and other data requirements, researchers should assess whether existing data could meet some or all of the data needs for analyses. A search for relevant data includes reviewing published literature and searching biologging databases (Harcourt et al., 2019) for relevant projects. Researchers can contact authors or data owners to discuss the proposed data use, confirm whether the data are suitable for the question, and request data sharing if needed.

3d. Use un-instrumented control groups.

Biologging studies should compare instrumented and non-instrumented animals whenever possible. Studies that compare instrumented versus non-instrumented physiology (e.g., body condition or stress hormones), behavior (e.g., foraging trip duration), and demography (e.g., reproductive success or survival) play a critical role in our understanding of tag impacts and confidence in the quality of biologging data (Caldwell et al., 2011). While not always possible, this practice can help detect instrument impacts and assure that biologging findings are generalizable to the larger population (Authier et al., 2013).

3e. Assess potential impacts on animals in managed care.

Testing the impacts of devices on animals housed in human care (e.g. zoos, aquaria, or other research facilities) affords researchers the opportunity to quantify physiological and behavioral impacts relative to instrument characteristics and attachment methods (McKnight et al., 2024; Van Der Hoop et al., 2014). While animals in managed care may not behave exactly like their wild counterparts, testing for short-term impacts may direct researchers towards small adjustments that can improve welfare during deployments on wild animals.

3f. Monitor studies regularly for signs of impacts.

Researchers should pay close attention to signs of physiological, behavioral, or demographic impacts and be ready to change protocols during the study to minimize impacts. Small changes such as attachment method (e.g., amount of glue used) and location (e.g., a few inches forward or backward) can result in large improvements for animal welfare (Cornelsen et al., 2022; Fritz et al., 2020).

3g. Report null impact results.

Publications that report negative impacts are more common than those that report null impacts, at least in part because of the difficulty of publishing null results (McMahon et al., 2012). In our literature review, 73% of studies found a negative impact of instrumentation, which likely reflects the bias against publishing null results. Null impacts should be reported whenever possible, whether as a part of a larger biologging study or separately. Null impacts should be determined through rigorous data collection instead of being assumed from anecdotal or observational evidence alone. Assessments and reports of statistical power can help to ensure that results from individual studies are not overstated (Cleasby et al., 2021). Furthermore, concerted community efforts to bring unpublished knowledge into the published literature (e.g., (Andrews et al., 2019; Horning et al., 2019)) greatly benefit the field of biologging by formalizing decades of experiences and sharing helpful anecdotes.

3h. Archive data according to minimum reporting standards.

Unlike fields such as genomics, biologging does not have a central data repository or standardization practice (Campbell et al., 2016; Lennox et al., 2017; Rutz, 2022). However, many publicly-searchable biologging databases exist that support public and restricted sharing (Harcourt et al., 2019) in harmonized, documented formats (Davidson et al., 2025; Sequeira et al., 2021a). Collected data should be stored in one of these repositories, or a generalist repository (e.g., Dryad), and include relevant reporting characteristics (Table 1). By making data publicly available whenever possible, and maintaining a point of contact on the platform, data can be more easily reused (Davidson et al., 2025). Reporting the recommended characteristics together with the original data in a structured format can enable queries across hundreds or thousands of projects (Beltran et al., 2025) and enable future evaluations of biologging impacts. Data-driven questions and global collaborations can help researchers to reuse or re-analyze data for new discoveries (Czapanskiy et al., 2022; Hindell et al., 2020; Kendall-Bar et al., 2023; Williams et al., 2020), which in turn increases the impact of data collected by animals.

3i. Utilize minimum reporting standards in manuscripts.

It is unreasonable to expect every study to evaluate every potential instrument impact. However, a minimum reporting standard for biologging instruments represents a single solution that supports all researchers. To this end, all biologging studies should include descriptions of instruments and attachment methods (Rutz, 2022). In addition to helping with future meta-analyses and syntheses, these guidelines can also facilitate efforts to refine development and deployment strategies in future research endeavors. Adopting a minimum reporting standard is a low-risk, high-reward next step for quantifying and minimizing instrument impacts. We detail our proposed minimum reporting standard and share an example in section 4.

3j. Summary: The need for standardized best practices across the scientific process

These best practices are broadly applicable regardless of the unique challenges of each discipline, study system, or step in the scientific process. They are directed at researchers or practitioners who are designing and executing biologging studies. Tag producers also play a role in enabling these best practices by documenting information about their devices that may be difficult or impossible to know otherwise, such as the materials and the upper and lower limits of signals produced. Model-specific device information is often available from commercial tag producers, but with varying ease of access and level of detail. We encourage device sheets to be made available online in as much detail as can appropriately be shared with the public for both current and older models. The sensor descriptions could be provided using existing standards such as the Open Geospatial Consortium's Sensor Model Language (SensorML). Such reporting could improve accuracy and consistency of reporting and allow researchers to extract information about studies that may not be contained in published papers.

4. A minimum reporting standard for biologging instruments

Using generalizations from the known impacts across taxa, we collated a list of instrument characteristics for consideration throughout the process of instrument development, deployment, and data dissemination. The minimum reported characteristics should include the instrument type, placement, weight, size, material, cross-sectional shape, manufacturer and model, attachment and detachment method, deployment duration, sensor list, signal production, and the intensity and frequency of signals (Figure 1; Table 1). Reporting characteristics such as the ratio between instrument/animal body mass or the ratio between instrument/animal cross-sectional shape, can help to evaluate, update, and develop “rules of thumb” that can be useful when developing new instruments and instrumenting new species. As biologging researchers, we are aware of the burden of additional bureaucracy imposed by reporting standards. We have attempted to be thoughtfully exclusive in selecting the reporting checklist categories so as to decrease the burden on researchers who may adopt it. The categories aim to provide structure and facilitate transparency, balancing the complexity of biologging tools with the highest priorities for future research.

4a. Sample reporting standard

To demonstrate the feasibility of a minimum reporting standard for instrument characteristics, we present a case study based on an ongoing biologging research project. This project, which does not assess instrument impacts, involves deploying SCOUT DSA Satellite Tags (Wildlife Computers) on juvenile northern elephant seals at Año Nuevo Reserve, California USA. Members of this project completed the minimum reporting standard checklist as a proof of concept. While not all categories were relevant to the study, the approximations nonetheless quantify the biologging instrument characteristics in far greater detail than is typically reported in study methods (Table 1). In the future, increased availability of instrument details from manufacturers could further simplify the use of the checklist for biologging researchers.

When the data from this project are published, they will be uploaded into a repository such as Movebank. Movebank and other biologging data repositories often allow researchers to report the details of instrument characteristics. We have included the Movebank term for each characteristic that has an equivalent in our checklist, as well as the Standard Framework term from (Sequeira et al., 2021b) when applicable. While this metadata can be useful for answering a variety of questions, collecting it is one of the only ways to ensure that future researchers will be able to assess the effects of instrumentation on animal welfare and data quality at scale. We therefore recommend that managers of biologging repositories cross reference our checklist with the requested or required metadata for data submissions. Researchers who do not plan to upload their biologging data to Movebank or a similar repository may instead consider attaching the checklist to their publications as supplemental material in a machine readable format, such as a .csv or .json file. Finally, efforts by journal editors and funders to champion reporting standards could provide a helpful incentive to improve rigor and reproducibility. For example, the *Cell* family of journals implemented the STAR methods reporting standard in 2016 (Marcus, 2016). These protocols became mandatory to address reproducibility and meta-analysis issues in other fields that are similar to what we experience as biologging researchers (Errington et al., 2021). Overall, broad adoption of these standard frameworks and practices, informed by decades of research on biologger impacts, will support rigorous biologging research into the future.

5. Conclusion

One of the greatest barriers to biologging impact meta-analyses and systematic reviews is that information about instrument impacts is often buried, anecdotal, or unpublished. In other fields, including those with rigorous open science requirements such as genomics, a lack of robust metadata has rendered up to 60% of shared data unusable (Toczydlowski et al., 2021). One development that could scale the impacts of our recommendations is the creation of a meta-database of biologger deployments and associated instrument characteristics (Rutz, 2022; Sequeira et al., 2021b). Such a repository could link these metadata to related papers and full datasets archived in other repositories. Gathering this information in one place would enable future meta-analyses and identification of effects that may not be detectable in individual studies. Further, it would encourage communication and collaboration between researchers across taxa, transport modalities, disciplines, and fields outside of biologging, such as agricultural animal research. In the meantime, minimum reporting standards are a low-investment, high-reward method for building robust biologging infrastructure. Eventually, standardized metadata will allow us to quantitatively refine our best practices and learn from past successes and challenges. Embracing open data and reproducibility will accelerate the pace of discovery in biologging data (Czapanskiy & Beltran, 2022), ultimately allowing researchers to save time and money, reduce the impacts to animals, and continue to publish cutting-edge science. As the field continues to evolve, we are at a crucial moment of opportunity where we can prioritize both rigorous data collection and the care of the animals that make our groundbreaking research possible.

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Tables

Table 1. Details of recommended animal, instrument, and data characteristics to report in manuscripts, with examples. To improve archiving and opportunities for meta-analysis, many of these details can optionally be stored along with data, for example in the reference data (deployment-level information) on Movebank. For clarity, we include terms used to store this information in Movebank ("Movebank term", MPIAB, 2024) or the standardized framework proposed by Sequeira et al. (2021) ("Standard framework term"). Device characteristics could also be provided in documentation provided by instrument manufacturers to improve reporting likelihood and accuracy.

Characteristic	**Description**	**Example**	**Movebank term**	**Standard framework term**
Animal characteristics				
Scientific name	Scientific name of the animal carrying instruments.	*Mirounga angustirostris*	animal taxon	scientificName
Common name	Common name of the animal carrying instruments	Northern elephant seal	animal taxon	commonName
Number of devices deployed on the individual	The number of instruments the animal is carrying during this deployment, including devices for which data are not analyzed in the current analysis. Characteristics should be reported in the "Device characteristics" rows for each instrument.	2 (Satellite tag + VHF)		
Animal deployment history	Number of times the individual has been instrumented, including the current deployment.	1 (current deployment)	Can be derived from the data if the full dataset is archived	
Animal handling time	Amount of time spent being handled, with	120 - 130 minutes	capture handling time	trappingMethodDetails

	notes on outliers			
Animal weight	Range weight of the animals measured at time of device deployment or other times. Can be recorded to calculate the device weight as a percentage of animal mass for each deployment.	67.6 - 273.6 kilograms	animal mass	organismWeightAtDeployment
Animal sex	Sex of the instrumented animals	Female, male		organismSex
Animal age class	Age class of the instrumented animals. Juveniles refer to animals who are pre-reproductive age.	Juveniles	animal life stage (other terms allow definition of exact, minimum or maximum date of birth or hatching)	organismAgeReproductiveClass
Number of animals instrumented	The number of animals who were instrumented with this configuration as part of the study.	32 animals		
Notes:				

Characteristic	Description	Example	Movebank term	Standard framework term
Device characteristics				
Type of instrument	A general description of the type of instrument being deployed.	SCOUT DSA Satellite tag, Advanced Telemetry Systems VHF tag	sensor type, tag model	instrumentType
Weight	Weight of the instrument in air.	210 (Satellite), 89 (VHF) grams	tag mass	
Dimensions	Length, width, and height/depth of the instrument. The antenna may be included as a separate measurement if necessary (i.e., for VHF tags).	Satellite: 85 (L) x 85 (W) x 27 (H) VHF: 35 (W) x 87 (L) x 21 (H) x 16 (Antenna) millimeters	Adding “tag dimensions” to the vocabulary	

Cross sectional shape	An estimate of the cross sectional shape of the instrument. These may be rounded, square, cylindrical, etc. Include whether the instrument is streamlined or complex.	Rectangular with rounded edges, streamlined.	tag comments	
Material	Material for instrument housing.	Water proof resin	attachment comments	attachmentMethod
Antennae	Presence of a flexible or stiff external antenna.	Flexible and stiff antenna	tag comments	
Buoyancy	Buoyancy of the instrument in seawater or freshwater (positive, negative, neutral)	Satellite: unknown. VHF: unknown	Adding "tag buoyancy" to the vocabulary; otherwise "tag comments"	
Orientation	Direction of instrument on the animal in relation to an external antenna.	Satellite: antenna facing forward VHF: antenna facing backwards	attachment comments	
Manufacturer	Instrument manufacturer.	Wildlife Computers (Satellite tag), Advanced Telemetry Systems (VHF tag)	tag manufacturer name	instrumentManufacturer
Model	Instrument model number or name.	SPLASH10-G-296 (Satellite tag), MM240B (VHF tag)	tag model	instrumentModel
Sensors	Parts of the instrument that collect data.	3-axis acceleration, depth, temperature, wet/dry	embedded in the data (e.g., sensor type)	See sections Horizontal sensors, Vertical sensors, Environmental sensors, Physiological sensors, Accelerometry sensors

Signal production	Sounds, lights, magnetism, or other signals produced by the instrument.	None	tag comments	
Notes:				

Characteristic	Description	Example	Movebank term	Standard framework term
Deployment characteristics				
Location on body	Placement of the instrument on the animal's body.	Head (Satellite tag), mid back (VHF tag)	attachment body part	
Archival or Transmitting	Whether the instrument transmits data through methods such as ARGOS, or archives the data until the instrument is recovered.	Transmitting, archival	tag readout method	
Photographs	Relevant photographs of instruments, placement, attachment, etc. included in an accessible format (i.e. jpeg).		deployment image	
Total weight	Weight of the instrument with additional hardware, such as a harness, collar, or housing.	Negligible extra weight (splicing tape, mesh, zip ties, fishing line)	tag mass total	
% of animal body mass	Approximate ratio of instrument mass to animal mass.	Satellite tag: 0.3% - 0.08% VHF tag: 0.13% - .032%	Can be calculated from tag and animal mass	
Instrument recovery	Number of deployed instruments that were recovered.	Of 32 satellite tags deployed, 28 were recovered from animals that returned. The remaining 4 animals were presumed dead of natural causes.	Relevant information can be stored in deployment end type, tag failure comments, animal mortality type	deploymentOutcome

Attachment method	Method for attaching the instrument to the animal. Include whether the instrument is sub or ex cutaneous.	Direct attachment (via epoxy) to fur	attachment type, attachment comments	attachmentMethod
Detachment method	Method for detaching the tags.	Removed manually upon recovery.	deployment end type, scheduled detachment date	detachmentDetails
Handling process	Description of typical handling process, including drugs used and time spent in human care. Cite relevant permits.	Healthy animals are chemically immobilized with an initial dose of telazol and sedation is maintained by follow up doses of ketamine and/or valium. Animals spend ~150 minutes in human care, which begins when they are immobilized and ends following an observation period post-handling. Tagging and sampling takes ~120 minutes. Elephant seal handling and sampling was approved by the University of California Santa Cruz Institutional Animal Care and Use Committee (#Costd-2009-1)	capture method	trappingMethodDetails

		and following guidelines set forth by the Society for Marine Mammalogy ethics committee. Fieldwork was carried out under National Marine Fisheries Service permits #23188.		
Duration of deployment	Length of time that the animal will carry/carried the instrument.	~229 (min: 107, max: 350) days	Actual deployment duration can be derived from the data or using deploy-on date and deploy-off date	TrackStartTime, TrackEndTime
Notes:				
Data characteristics				
Instrument data format	File type of raw data output.	.wch		
Instrument data location	Location of raw and processed data, including DOIs. (e.g Ocean Tracking Network, Movebank Data Repository, Dryad repository)			references, citation
Other essential data	Instrument calibrations and metadata that might be needed to analyze the raw or processed data, including details such as time zone.		tag calibration, geolocator calibration, tag settings	See sections Environmental data calibration, Physiological data calibration, Accelerometry data calibration
Other essential data location	Location of calibrations and other metadata.			otherDataTypesAssociatedWithDeployment

Table 2. Examples of impacts to instrumented animals at different disciplines.

Discipline	Examples of impacts
Physiology	Changes in thermoregulation, metabolic or energetic costs, hormone production (i.e., corticosterone), and/or body condition (body mass, growth, injury)
Behavior	Changes in locomotion (speed, endurance, ability), grooming, foraging, social behavior, provisioning to young (directly and indirectly), mating, predator alert and escape (crypsis, grouping, attraction), and/or athleticism (running, acceleration)
Demography	Changes in fitness (in individuals and populations), survival, recruitment, and breeding success, and/or sex ratio

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