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Commentary

Burden of a failed error culture in biologging

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Driven by technological advancement and low cost, biologging has rapidly transformed the study of animal behaviour and ecology, providing unprecedented insights into wildlife and aiding conservation efforts and ecological research. However, despite its development, biologging still faces ethical and methodological challenges, including the lack of error reporting, inconsistent standards and insufficient consideration of animal welfare. In this study, the importance of a robust error culture in biologging to address these issues was highlighted. In addition, four key directions for action were proposed: (1) establishing a biologging expert registry to enhance collaboration and knowledge sharing, (2) implementing preregistration and postreporting of studies and devices to reduce publication bias and improve transparency, (3) demanding industry standards for biologging devices to ensure reliability and minimize harm and (4) developing educational programmes and ethical guidelines tailored to the unique challenges of biologging research. By continuously implementing the 5R principle (replace, reduce, refine, responsibility and reuse), the biologging community can balance technological progress with ethical responsibility. These measures aim to improve research quality, safeguard animal welfare and foster a sustainable future for this critical field.

Animal biotelemetry, which is generally known as biologging, is rapidly growing (Bridge et al., 2011; Ropert-Coudert & Wilson, 2005; Wilmers et al., 2015). An increasing number of animals are equipped with electronic devices, resulting in soaring data volumes and publications (Joo et al., 2022). This success is clearly driven by technology and amplified by plummeting prices for devices and a thriving diversity of commercial and academic suppliers (Cooke et al., 2004). The combination of miniaturized electronic sensors, increased battery capacity and low energy consumption promotes the developments of smaller, cheaper and long-lasting devices (Ropert-Coudert & Wilson, 2005). Technological innovation extends to data transmission networks, from cell-phone networks and the internet of things to global satellite-based communication networks, which allows data reception from anywhere, anytime (Elias et al., 2017, pp. 247–258; Wild et al., 2023).

The creativity of engineers is further fuelled by a continuous supply of novel sensors that can be added to devices deployed on animals, opening up new avenues for research (Wilmers et al., 2015). This serendipitous alignment of circumstances has created a field full of opportunities, thereby accelerating scientific discoveries and promoting the 'golden era' of biologging (Wilmers et al., 2015). The transformative power provided by the ubiquity and affordability of biologging devices is boundless, offering increasing options for using better technology at lower costs (Kays & Wikelski, 2023). The field of technology-driven animal research in the wild has reached a stage where we believe the time being ripened to question and reflect on how this rapid growth and development can and should be achieved sustainably and ethically (Palmer & Greenhough, 2021; Soulsbury et al., 2020; R. P. Wilson & McMahon, 2006).

THE RISE OF BIOLOGGING

Studying animals in their natural environments is essential to understand the proximate and ultimate mechanisms that defined

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life on our planet in the most relevant of contexts, as well as the reason for why biologging, formerly known as niche, has arrived in the mainstream (Cooke et al., 2004; Kays & Wikelski, 2023; Wikelski et al., 2007). Biologging devices attached to animals provide invaluable and irreplaceable knowledge on animal behaviour, physiology, neurobiology, ecology and evolution in the wild (Beltran et al., 2025; Costa-Pereira et al., 2022; Hawkes et al., 2021a; 2021b; Rattenborg et al., 2016; Vyssotski et al., 2009; Wikelski et al., 2007; Wilson et al., 2015). Many aspects of biologging research are directly related to global change and the challenges that growing human impact poses to nature and people (Tucker et al., 2018). Without biologging, the ability to protect species in their natural habitat would be severely impaired (Wilson et al., 2015). Apart from scientific purposes, biologging can be used to help decision-makers decide on the placement of conservation areas, and it serves as a corner stone in monitoring and documenting change and mitigating human–wildlife conflicts; thus, biologging is considered as an effective tool to prevent animal death, as it provides information on the mechanism underlying population decline (Altizer et al., 2011; Bengtsson et al., 2016; Jetz et al., 2022; Morelle et al., 2023; Tucker et al., 2018; Wilson et al., 2015; Yanco et al., 2024). These wide range of topics can be addressed by understanding physiological limits and reaction norms, animals' processing of information at the sensory and neurological levels and how, when and why animals move in relation to changing environmental conditions (Hawkes et al., 2021a, 2021b; Nathan et al., 2008; Rattenborg et al., 2016; Vyssotski et al., 2009). Biologging devices document and provide unprecedented insights into the behavioural heritage of the natural world linking us to the living planet, where, irrespective of affordability, everyone can appreciate the importance of ecological and natural phenomena, the physiological performance of animals and the impact that they have on humans and vice versa (Jetz et al., 2022; Yanco et al., 2024).

THE FLIP SIDE OF PROGRESS

Often, when choosing which biologging device to deploy, how to capture and handle an animal (particularly when working with new species) or how to attach a device, the decision-making process is largely based on the amount of experience acquired previously (personal or learnt via word of mouth; Andrews et al., 2019; Cullen et al., 2023; Fijn et al., 2024; Houstin et al., 2022). In addition, decision and advancements are based on trial and error, as scientists pioneer new research avenues using a novel technology on species that have never been tagged (Andrews et al., 2019; Beltran et al., 2025; Ropert-Coudert et al., 2009).

The ethical and environmental impacts of biologging have also been increasingly reported (Casper, 2009; Longarini et al., 2023; Palmer & Greenhough, 2021; Payne et al., 2024; Portugal & White, 2022; Soulsbury et al., 2020; R. P. Wilson & McMahon, 2006). Considering that biologging relies on the use of animals to obtain data, ethical considerations must be a core element of the field (Parker & McElligott, 2023; Petkov et al., 2022; Richter et al., 2025). However, the drive for data collection overshadows equally important considerations related to animal welfare.

A recent review of the widespread use of biologging devices (Arrondo & Pérez-García, 2025) has reported that the majority of animals equipped with biologging devices did not contribute to scientific publications, leading to the trivializing of the use of biologging devices and the associated burden on animals. The focus on publication output overlooks the potential benefits of biologging in important aspects such as monitoring and management. However, Arrondo and Pérez-García (2025) emphasized an important and undervalued consideration: What are the expected achievements for the planned use of animals in biologging studies, regardless of the context and purpose of the use of biologging? Ultimately trying to turn back time on the fact that biologging has become mainstream is futile.

The main body of the current discourse on ethics on animal use in biologging focuses on refining aspects directly pertaining to the welfare of animals considering ethical approval processes and discussing the valuing system where a putative (scientific) outcome is weighed against an imposed burden (Arrondo & Pérez-García, 2025). This momentum in the field happens against the background that the uptake and implementation of the 3Rs principle, as well as the ARRIVE and PREPARE guidelines, which aimed to improve animal welfare and research quality, has decreased in wildlife research compared with its laboratory counterpart (Lindsjö et al., 2016; Percie du Sert et al., 2020; Smith et al., 2018). This phenomenon is due to a mismatch between the controlled lab conditions that these initiatives have originally been tailored to and proposed for, as well as the inherent complexity of working in the wild. Extending the existing principles to the 5R principle specific to the area of wildlife research using biologging can reduce animal burden.

The 5R principle is an extension of the 3Rs.

(1) Replace: assess whether biologging using animals is essential for answering research questions. Prioritize the use of existing data through collaboration and permissions before deploying devices on animals. Ensure questions can be reliably answered with the planned number of animals and devices.

(2) Reduce: minimize animal use by advancing technology, setting device standards and improving data collection efficiency. Clearly articulate hypotheses and verify whether methods need the required number of animals.

(3) Refine: reduce burden on animals by improving device technology and wearability/comfort and enhancing deployment expertise amongst researchers.

(4) Responsibility: establish and uphold ethical accountability throughout the research, prioritizing animal welfare and adhering to institutionalized ethical standards.

(5) Reuse: emphasize data reuse to improve reproducibility, reduce animal burden and accelerate scientific discovery.

Apart from these important considerations on ethics and despite the traction that biologging has gained in studying animals in the wild, the near absence of a reporting and error culture is striking. Although journals and societies are becoming rigorous about the declaration of ethical approvals and publishing detailed description of methodology, failures, wherein animals had been used but no or inadequate data were obtained, are neither publicly documented, nor requested to be reported (ASAB Ethical Committee/ABS Animal Care Committe, 2020; EJournal of Animal Ecology, 2021). This focus on successful publishing leads to the 'file drawer effect' (Csada et al., 1996). Failures, when shared and learnt from, can increase the return on investment of research financially and intellectually, which should be considered an indispensable cornerstone in (wild) animal welfare.

In this study, the lack of error and reporting culture was addressed and discussed from three interconnected perspectives: (1) animal welfare, with a focus on the elements relevant to the individual animal being used for research; (2) technology, mainly the aspects that have rarely been part of a discourse beyond the effects of weight and shape; and (3) the human factor, in relation

to largely neglected foundational aspects of the cultural and professional standards in pursuing biologging research.

On the basis of a nonrepresentative and personal assessment of the status quo in these three areas, four action items that could address the challenges of the sustainable and ethical growth of the biologging field were proposed.

ANIMAL WELFARE

All biologging researchers are familiar with the difficult realities of our work, as we have injured or lost animals and know of colleagues who have. Yet, reports on failure rarely surface in the field (Crofoot et al., 2009; Fijn et al., 2024; Houstin et al., 2022). Failure is mostly reported through hearsay or experience. The top priority of researchers in the field is and should be the welfare of their study animals. However, given the trial-and-error nature of acquiring experience and improving procedures, combined with the lack of transparent reporting of (negative) experiences in publications and communication among researchers, mistakes are made because of 'reinventions of the wheel.' As mistakes happen and lessons are learnt individually, the community is not invoking the full potential because of the absence of the culture of openly sharing experiences or demanding for and engaging in systematic reporting (Christensen & Fantuzzi, 2024; Lameris & Kleyheeg, 2017; MacCallum, 2010; Payne et al., 2024).

Biologging studies begin with the capture and immobilization of animals, marking the beginning of animal burdening. Occasionally, animals succumb to handling stress, which is referred to as capture myopathy, a diagnosis for a malignant outcome of stress from handling animals with a lethal outcome (Breed et al., 2019). Hence, any biologging research begins with burdening animals through capture and continues throughout the deployment of biologging devices, which inflict a multitude of documented consequences on their survival (Lameris et al., 2018), social behaviour (Lameris & Kleyheeg, 2017), reproduction (Barron et al., 2010) and energy expenditure (Barron et al., 2010; Kyte et al., 2019). As proposed by various existing publications and initiatives, biologging should reduce its impact to ensure the welfare of animals, foremost as a moral obligation towards every living being (Petkov et al., 2022; Soulsbury et al., 2020), and to minimize bias on the data and the insight gained from them. At present, reporting on the entirety of the process from capture through immobilization and device attachment, all of which are specific to the species, is neither common nor considered necessary, particularly when it comes to reporting on negative outcomes. However, the lifestyle of the animal in the context of the technology used even beyond the time of data collection should be considered. The lack of consideration of the impact of biologging devices on all aspects of an animal's behaviour can cause harm and discomfort to animals and can limit the generalizability and reproducibility of findings because the device itself altered or hindered the animal's normal lifestyle and social interactions. For example, in cheetahs, although a 3% device-to-body-mass ratio had little impact on a stationary animal, quick acceleration during hunting amounted to forces up to 54% of the body mass exerted on the animal (Wilson et al., 2021). Furthermore, these impacts could have cascading and multifarious impacts on other species down the food chain if hunting success is affected. Finally, the impacts of biologging on nonresearch target individuals and species should also be considered, whether through trap bycatch (Hotopp et al., 2022) or through indirect negative welfare effects after capture and release (Soulsbury et al., 2020).

TECHNOLOGY

Another almost accepted aspect of working with biologging devices in the wild is that a certain, sometimes substantial, proportion of the devices deployed on animals will never deliver actual data. Although researchers embark on expensive expeditions, work under potentially dangerous conditions to catch and equip animals with impactful devices, these devices yield little or much less required data than needed to answer scientific questions. Endless intangible stories of epic technology failure are shared orally among researchers, such as devices stopping to work after being deployed on animals, release mechanisms not working at all or at the wrong times, firmware errors leading to useless data, attachments failing, sensors drifting with time and deteriorating and animals getting trapped in their own biologging attachments. These device failures mark an unnecessary harm to the animals and a complete loss and waste of research efforts. For years, we think biologging devices had and have to be considered as experimental electronic devices with no liability or guarantee to work as advertised regardless of the promises of the vendors. In fact, under the pressure for high impact publications, research is often driven by pushing technological boundaries rather than by answering fundamental biological questions. Given the lack of reporting, there is no objective, independent or quantitative prediction of how well devices perform despite existing methodologies aimed to do precisely that (Bidder et al., 2014). The diverse companies and workshops catering to biologging, the rapid development cycles, the varied deployment conditions and taxa and the input of individual field biologists create a noisy backdrop, making it impossible to objectively assess device reliability and acceptable failure rates.

Although some companies refund the price of failing tags, the expenses that a failed expedition entails, which is due to a technology failure, has no recompensation, such as the compensation for the animals burdened with dead weight or the environment for the pollution caused by electronic waste. Furthermore, failing technology can include killing animals to prevent further suffering (https://www.swissinfo.ch/eng/sci-tech/deer-study-goes-awry/36812992).

HUMAN ASPECT

With the development of more sophisticated devices, a steep learning curve has been observed. In the time preceding the wide availability of commercial collars, we often relied on 'do it yourself' and experimental engineering to push the boundaries. Thus, we will continue to be in uncharted territories, try, fail and learn from our mistakes. However, as the field of technology-driven animal research matures and grows, the mechanism by which the biologging community can initiate a more systemic and systematic approach to error culture when it comes to disseminating knowledge and attaching state-of-the-art technology to animals must be considered. Most researchers, rather than through standardized curricula, learnt tagging through informal apprenticeships under experienced mentors, complemented by an individual study of publications and refined with individually acquired experience from the field. Consequently, there is diversity in the ways field work is pursued, a variation that could represent a fertile ground for evolving better procedures and improve, if there

was a reproducible and quantitative approach to speaking about the art of catching and handling animals, best practices in using devices and making wildlife wearables better.

TOWARDS A (BETTER) ERROR CULTURE

As biologging is indispensable and its application will continue to grow, the path of progression must be considered. No one is in a better position to propose improvements than the biologging community itself. If we do not attempt to improve, then one day rules, and regulatory measures might be imposed formally through legal means and informally through public admonishment rather than by optimizing the balance between welfare and research necessity. Our freedom in what we do comes with a responsibility that we must begin to take more seriously.

Four Action Items

We must acknowledge untapped potential for improvement such as the endorsement of an error culture that holistically improves our research by establishing better communication and exchange tools to maximize our ability to improve (Fig. 1).

We acknowledge that publishing our failures or an external auditing procedure in case of failures cannot be implemented in the short run, albeit in the interest of our field's progress. However, we suggest clear improvements to the current don't ask, don't tell, 'elephant in the room' status quo.

A biologging expert registry could be a major step (Fig. 2), which, combined with a request for preregistration, result (post-) reporting and publication bias reporting (Fig. 3), would clearly enhance our knowledge pool and allow us to overcome the complete absence of an error culture (Nosek et al., 2018). These two most important measures would provide the basis for a quantitative assessment based on which we could define success and prevent committing more failures in the future (see also the fourth proposal). Another pivotal action item is the demand for industry standards from device manufacturers (Fig. 4). Finally, we must conceive an educational and training programme tailored to the demands and required skills that biologging poses towards the researchers, including the mechanism by which we collaborate and interact (Fig. 5). This action will require targeted research into animal welfare tailored to the research of wild animals, providing the academic backdrop that an educational training programme would need.

BIOLOGGING EXPERT REGISTRY

A feasible option that could improve communication in our growing community would be a registry of biologging experts (Fig. 2) cross-linked to various existing or emerging repositories and databases through individual identifiers such as ORCID. A registry could serve as a point of contact for other researchers and as a reference for ethics committees and could help propagate relevant information efficiently and provide ethical and legal entities as a reference to the experience and contemporary continued education on relevant matters of animal experimentation and ethics. This registry could be managed by the International Biologging Society, the Animal Behavior Society or the Association for the Study of Animal Behaviour. The registry could archive relevant information about biologists, veterinarians and

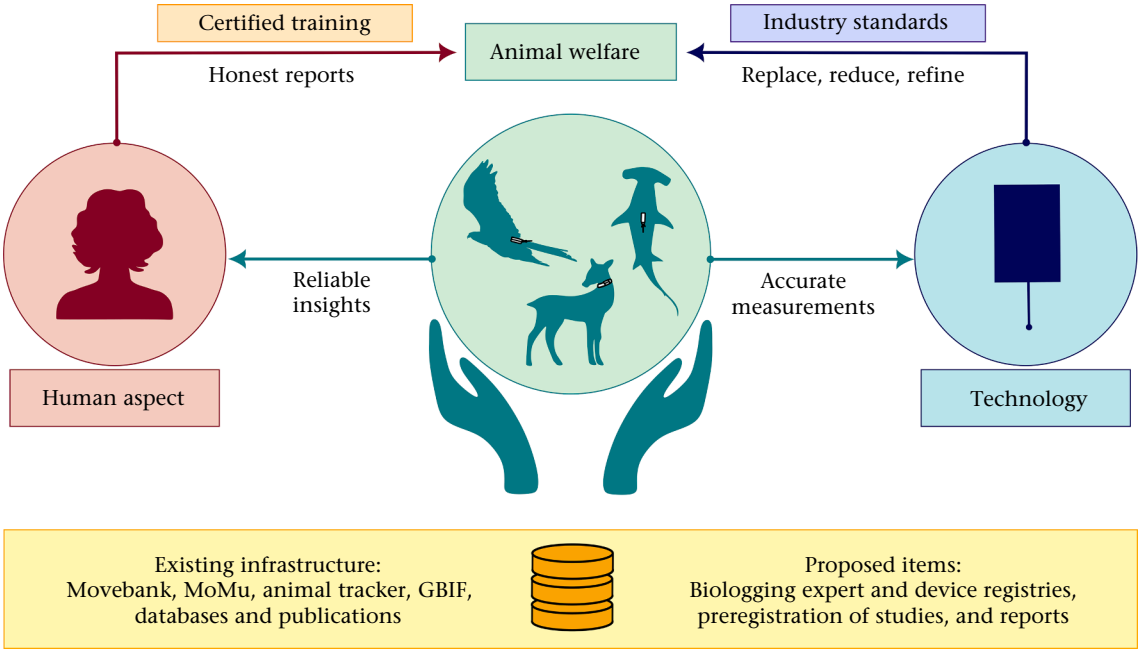

Figure 1. Comprehensive approach to ethical and effective animal biologging practices, emphasizing animal welfare as the central priority. The harmonious integration of human expertise and technological advancements can enhance animal welfare while collecting valuable telemetry data. In particular, a biologging expert should be equipped with certified continuous training and committed to transparent and systematic reporting. Tag devices should meet industrial standards and should be continuously improved. The combination of human and technology aspects alleviates the burden on animals and provides reliable insights into science and its applications while supporting further technological innovations through precise sensor measurements. Existing and proposed infrastructures support the application of the suggested framework. Platforms and databases are assisted by the hereby proposed registries of biologging experts and devices, along with the preregistration of studies and complete reports. The following colour coding is used throughout the figures: Green indicates animal use and welfare; red represents human aspects; blue represents technology and telemetry devices; purple represents industrial standards; orange represents biologging training, and yellow represents infrastructures. MoMu is the movebank museum representing an extension to the animal movement database with the purpose to provide a digital life history museum as a repository to store the heterogeneous yet important metainformation related to biologging of animals in the wild. GBIF is the global biodiversity information facility, providing open access to data about all types of life on the planet.

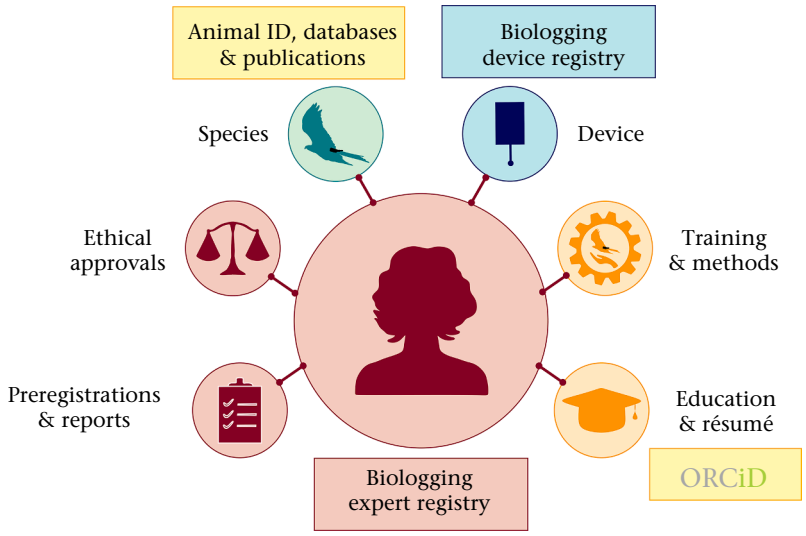

Figure 2. Potential biologging expert registry. Each expert's profile includes their personal information, such as education path, résumé/CV and ORCID profile. Each expert's experience with study species and tags is documented, with links to the proposed tag/device registry, along with cross-references to unique IDs for tagged animals, relevant databases and resulting publications and data repositories. The registry (1) details the expert's experience in specific handling/attachment methods, including continuous training records, (2) contains preregistrations of animal studies, transparent reports and the associated ethical approvals and (3) aims to facilitate communication and feedback within the global biologging community.

animal caretakers who were involved in biologging research and their field of expertise (species, tagging methods, devices experience etc.). Considering privacy rights, individuals could be identified and contacted by peers to foster the exchange of expertise concerning methods (capture, handling, marking, biologging implantations, anaesthesia, etc.) and materials (devices and harnesses).

Pertaining to international field work, such a linked registry could help identify relevant experts across national boundaries and different regulation schemes. In addition, it provides information about the type of field actions and methods such as capture, handling, marking, invasive and noninvasive technology; attachment methods and anaesthesia, as well as the experiences of researchers with working in specific field sites. This registry could be linked to the tag/device registry (Rutz, 2022), allowing researchers to identify who has used which kinds of hardware and share experience and expertise. Likewise, the unique animal identifiers of handled animals could be cross-referenced (Wikelski et al., 2024), allowing researchers to follow up on events associated with specific individual animals, including the roles that biologgers played in their lives. Ideally, the registry would cross-reference to the studies that have emerged from the activities a person was involved in, regardless of whether they were named authors or not (in addition to the listing publications or referencing ORCID iDs), including the reuse of data that they contributed to by consortial and comparative initiatives, thereby

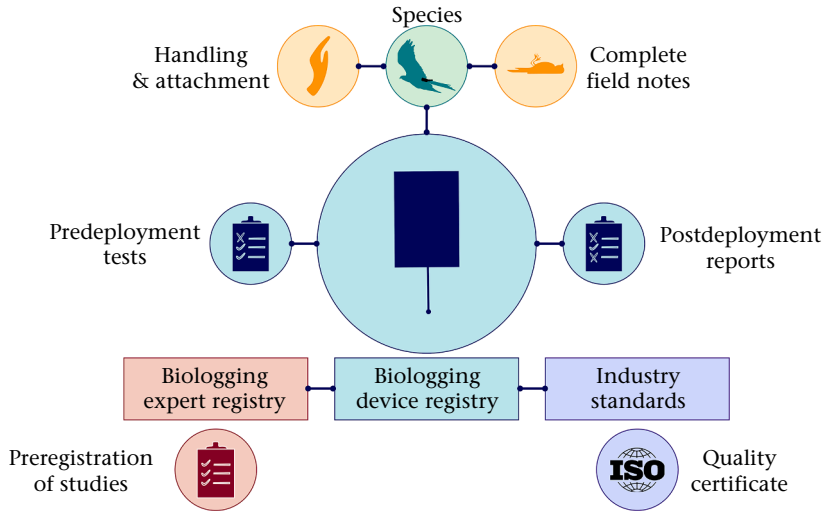

Figure 3. Preregistration and postreporting registry at the device and animal use levels. Only devices meeting quality certification standards required by industry regulations are included. Each device is connected to the documentation of predeployment tests, detailed attachment procedures and postdeployment reports. For each device, the registry includes the biologging expert identity and the animal species it has been applied to, along with detailed handling methods. Each preregistered study is also cross-linked to unique IDs for tagged animals, relevant databases and resulting publications and data repositories. Complete field notes are incorporated, including records of negative outcomes, such as device failures or animal losses in the field. The proposed registry is naturally integrated with the biologging expert and device registry, as it aims to facilitate communication and feedback within the global biologging community.

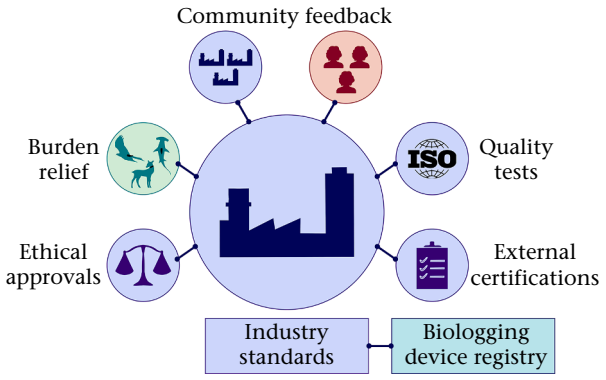

Figure 4. Suggested industry standards for biologging device production. To be included in the biologging device registry, tags must have certifications for standardized quality and testing, which are validated by external neutral companies, and must obtain ethical approval for animal use. Manufacturers must collaborate with other industries and the community of biologging experts, reporting the mechanism by which feedback and shared experiences have been applied to improve technology and reduce animal burden.

increasing visibility and ownership beyond the role of co-authorship. This method would require the registry to accommodate adding publications to the profiles other than author roles, for example, data contributor, technical assistance, paid assistance and veterinary oversight.

Preregistration of Biologging Devices and Animal Use

The problem of biased positive reports and unreported failures is that it takes far too long for the field to react to singular, yet important discoveries, which requires a change in procedures to penetrate the field quickly. This problem is similar to the 'file drawer effect' (Csada et al., 1996), where a bias towards the desired outcomes leads to the publication of false positives and faulty science (Smaldino & McElreath, 2016). However, in this case, the negative externality is the welfare of animal research subjects and the wellbeing and time of researchers. Considering that new biologging studies follow published methodologies, a positive reporting bias will manifest in suboptimal or outright detrimental procedures for a long time despite existing knowledge. Purging knowledge that was deemed or proven as detrimental from the knowledge base is hence difficult. The publication bias against negative results also indicates that experiments and procedures get repeated many times with no prospect of success.

As with regard to the file drawer effect, the only solution is collective action and institutional change (Kohrt et al., 2023; Smaldino & McElreath, 2016; Smaldino & McElreath, 2016). Thus, we should continue to systematically question what we do and how we do things rather than following the trodden paths of days past (Fig. 3). In addition, we should aim for a system that follows the most recent quantitative and peer-reviewed assessment of procedures rather copying historic and possibly highly problematic yet published methodologies. Adopting a reporting system that allows standardized and systematic reporting of negative results is important. With the advent of large language models, there are new possibilities for quantitative analysis of narrative reports and data aggregation. Although irrelevant and small, storing narratives about field events from capture over handling to deployment, including images and videos of technology and all the circumstantial experiences when attaching devices to animals, could be summarized and quantified efficiently across languages and media.

A fundamental step to improve drug discovery was the FDA-imposed registration, result reporting and publication bias of clinical trials (The Food and Drug Administration Amendments Act; Zou et al., 2018). Introducing this measure led to a marked improvement in all aspects of drug discovery and in the ratio between trials and successful discoveries, thereby reducing cost and leading to better treatments. Likewise, the preregistration of biologging devices (e.g. GPS position logging devices combined with the suggested tag-registry), which requires researchers to publish the intended use of biologging devices on animals, would provide the opportunity for relevant researchers to invoke synergies. A mandate on following up on the preregistered devices after deployment would improve performance by quantitatively assessing the success-to-failure ratio. The bias that is introduced by failing to publish negative results could be reduced. In addition, such a registry could actively suggest links among technology, targeted taxa, attachment methods, researchers and metadata without disclosing raw data.

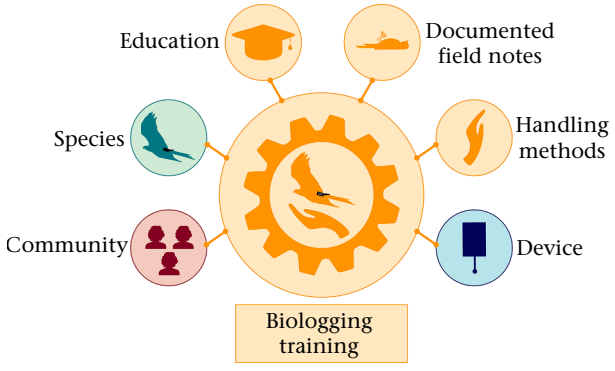

Figure 5. Suggested educational programme for biologging experts. Comprehensive training integrates technological expertise with hands-on experience; therefore, it is closely linked to the biologging expert and device registries. The programme includes collaborative lessons and workshops among specialists in similar study systems, facilitating the exchange of species-specific knowledge, handling methods and different device applications. A robust theoretical foundation is given through educational materials and documented field notes, equipping researchers with the tools for efficient and ethical biologging practices.

Demanding Industry Standards

We should define the acceptable ratio between the burden on animals and the volume, as well as the quality of the data obtained, and refrain from buying cheap technology that is likely to fail or deteriorate. It is not acceptable (and unlawful in the European Union) to perform a simple economic calculation weighing a low unit price for accepting high failure rates or inadequate data; the wellbeing of the handled animals is a currency that cannot be ignored. The biologging community should demand that industry must define standards and impose external auditing and certification for devices brought to the market. This measure could enhance accountability (Fig. 4). Providers of devices catering to the wide community representing off-shelf and market-established units that can be bought and deployed currently with little to no oversight should self-impose industry standards, certification and registration.

Technological advancements can remarkably reduce burden (Bograd et al., 2010; Williams et al., 2020). The reduction in size and weight and the increased reliability of devices are responsible for the surge in biologging research activity. By further improving device-to-animal mass ratio and by adjusting their shape and size, new devices have yielded new opportunities that were unimaginable a decade ago. However, the miniaturization of biologging

devices has not decreased the device-to-body mass ratio borne by animals, which is a measure that is arbitrarily set at a maximum of 5% (for terrestrial) or 3% (for birds), representing the maximum device-to-animal mass ratio (Meierhofer et al., 2024; Wilson et al., 2021). As a community, we have invested technological advances in equipping smaller species (Portugal & White, 2018), thereby maintaining the burden. We could do better and rein in our greed for data, which is paid for by heavier than necessary devices because of additional sensors and larger batteries for longer deployments while maintaining the weight thresholds. The relative weight ratio is not even considering the potential improvement that could be achieved by harnessing the effects of shape, form and placement and the refinement of attachment method in the interaction with the species-specific mode of movement and the media it moves through (Kay et al., 2019; Longarini et al., 2023; Mizrahy-Rewald et al., 2023).

As we will continue to rely on experimental technology to achieve groundbreaking research, we should expect experimental and pilot devices to meet certain baseline published and agreed upon standards and procedures before being considered fit for deployment. Testing devices on any animal has to be strictly considered as an animal experiment requiring the same level of ethical approval as biological research projects do. Ratings or labels indicating different levels of 'quality' would help distinguish between experimental and established devices with clear requirements that have to be met and come with liability in case of failure or malfunction.

Although requesting standards will increase unit costs, the benefits and positive externalities to animals, researchers, funding sources and research quality will justify the investment and may lead to lower per datum expenses when the full cost of the research life cycle is accounted for environmentally and economically. Standardization would also level the industry playing field by preventing price-based competition between the technology providers that compromise diligence in craftsmanship and testing at the cost of animal welfare and research quality. Demanding standards from the industry will further provide justification and credibility to the permitting authorities and ethical commissions that assess research proposals to enforce the use of devices considered and certified as fit for purpose. By engaging in pre and postreporting, a more realistic and quantitative assessment of the percentage of devices that can provide data given the proposed procedures and species involved could be estimated by weighing the risks against the realistically expectable reward based on methods such as the Biotelemetry Event Tree (Bidder et al., 2014).

Educational Programmes and Defining Ethical Standards for Our Field

As the field and the number of researchers deploying devices grow, we must define and formalize the qualifications, training and skills required to be considered as a biologging expert (Fig. 5). To our knowledge, no curriculum or institutionally defined education programme that addresses the art of animal wearables, explains the best mechanism in deploying devices to animals and identify the effects of using alternative methods has been established. As laboratory animal science systematizes the standards involving care, housing, feeding and medical treatment of laboratory animals, we should aspire to establish systematic research to quantify the impact of studying wild animals and subsequently define and refine education programmes from a holistic perspective (Erichsen & Hopla, 2021; Forni, 2007). If biologging focused on the study of wild animal welfare, then it would not only advance understanding of the external factors affecting wild animal welfare, such as human disturbance, but also lay the groundwork for a more institutionalized, systematic and evidence-based approach, extending to a self-reflection of how biologging affects wild animal welfare (Beaulieu & Masilkova, 2024). Refinements in relation to deploying biologging devices on animals, particularly the experience and expertise of wildlife biologists or veterinarians and the continued improvements in attaching devices to animals, are a crucial aspect that affects data quality and quantity. An educational programme would also establish the culture of preregistration and postreporting as an integral part of the responsibility that is expected from biologging experts, which provides the quantitative basis for progress. Furthermore, we should aim to challenge old habits and increase the pace of improvements in handling and studying wild animals, which could be much improved if it was evidence-based, academically organized, quantitatively assessed and formally developed. Some current legislation and the way authorities interpret them make training for scholars in handling and deploying biologging devices as part of ongoing research in the wild very difficult. However, mandated courses aimed at acquiring skills and knowledge are currently and mostly applied to laboratory animals (mice and rats) or other taxa that have little relevance for a specific research project, but are considered qualifying to catch, handle and deploy devices on wild animals.

Regulatory Suggestions

With the growth of the biologging field, the existing reporting procedures and trainings are mainly geared towards working with laboratory animals and the mandated qualifications that allow researchers to conduct animal experiments in laboratories and animal housing facilities, thereby creating an increasing mismatch between the true requirements of the field. The legal and formal procedures are becoming an obstacle that needs to be addressed. The ethical applications, preregistration and postreporting procedures, administrative forms and legal documents should be required in this field to improve the welfare and quality of research, particularly the technology-driven study of wild animals. Defining these procedures will also prevent competition nurtured by different levels of national requirements that may incentivize the field to move into studying in certain places based on the administrative load (or the lack thereof) on the researchers and their budgets rather than more reasonable objectives. With regard to laboratory animal welfare, the same considerations have given rise to the transition of the original 3R principle to the principle of 4Rs with an emphasis on cultivating the moral responsibility that working with animals entails globally (Kang et al., 2022).

The Federation of European Laboratory Animal Science Associations explicitly considers sample sizes as an important aspect of animal experiments, as well as the quantification of the ratio between burdened animals and realistic estimations of data obtained (Bidder et al., 2014). By the time technology fails and the abovementioned sources of failure accumulate, the percentage of success with regard to data obtained per individual burdened can drop dramatically. Apart from reporting successes and failures, the description of attachment method and procedures, the materials used and the duration of handling should all be catalogued and reported as part of the crucial metadata along with the raw data. These details should be part of a reproducible science approach, as they fundamentally affect the quality and volume of the data with implications on cross-comparability of study results.

The proposed four action items could be embedded in the existing landscape of databases, where data, people, devices and industry can be better connected by using intelligent and intuitive software solutions and AI. Consequently, the data collected on individual animals could be linked to their histories based on their

unique animal ID (Wikelski et al., 2024) and to researchers, studies and devices (Rutz, 2022), all of which have associated meta information.

Ethical Note

This commentary does not report new empirical research involving animals. Instead, it discusses ethical and methodological issues in the field of biologging and animal behaviour research, focusing on animal welfare and responsible research practices.

Conclusions

As the field of animal biologging continues to grow and evolve, a robust error culture that fosters open communication about failures and prioritizes animal welfare must be established. Thus, technological advancements can translate into ethical and effective scientific progress. The proposed action items, including the biologging expert registry, standardization efforts and adoption of the bespoke 5R principle, represent the crucial steps towards a more responsible, inclusive and transparent research community. Burdening animals with biologging devices should aim to deliver data that are reliable and possibly definitive. The replication crisis (Kelly, 2019; Yang et al., 2024) makes ethical considerations directly related to the scientific ambitions of the biologging field. Given the logistical challenges and costs associated with tagging and tracking animals, we often face challenges with statistical power and robust experimental design (Yang et al., 2024), which are shared among the field of ecology and evolution (Kelly, 2019; Yang et al., 2024). However, according to Yang et al. (2024) and Nakagawa et al. (2024), small studies can still be valuable if we prioritize transparent reporting of all results, including effect sizes and CIs, regardless of whether they are positive or negative, as well as actions that would counterargue the trivialization accusation (Arrondo & Pérez-García, 2025). In addition, we must emphasize theoretically informed, well-designed studies over mere statistical significance and encourage the publication of all findings to combat the file drawer effect (Smaldino et al., 2019; Smaldino & McElreath, 2016; Stewart & Plotkin, 2021).

By investing in an error culture, we can facilitate more comprehensive meta-analyses that aggregate data from multiple (also small-scale and possibly unpublished) studies, thereby increasing statistical power and enhancing the replicability of our findings without further use of animals (Yang et al., 2024). The biologging field would greatly benefit from embracing open science practices, thereby increasing its credibility. The transparent reporting of protocols, preregistering studies, using registered reports, archiving data and code and establishing solid educational and ethical research-based foundation for the use of animals in our field are considered important. How we do our research remains to be decided by the community; the four action items represent the points and topics that we could start considering and talking about.

Establishing an error culture has to be a community-driven and democratic process that balances the costs and benefits considering the wide range that biologging is serving. The community should strive to reduce questionable research practices, detrimental competition and misguided incentives. Naturally, achieving these goals comes with allocating worthwhile resources, particularly time and money, into activities yielding long-term benefits to the field, thereby elevating quality over quantity at the cost of not being able to publish as many papers in as little time as possible. There is no option for reaping benefits without committing to carrying the costs.

Author Contributions

Brendan J. Barrett: Writing – review & editing, Writing – original draft, Conceptualization. **Wolfgang Fiedler:** Writing – review & editing, Writing – original draft, Conceptualization. **Francesca Frisoni:** Writing – review & editing, Visualization. **Zoë Goldsborough:** Writing – review & editing, Writing – original draft, Conceptualization. **Inge Müller:** Writing – review & editing, Writing – original draft. **Kamran Safi:** Writing – review & editing, Writing – original draft, Conceptualization. **Martin Wikelski:** Writing – original draft, Resources. **Daniel Zuñiga:** Writing – review & editing, Writing – original draft.

Data Availability

This article is not based on data collected or analysed.

Declaration of Interest

All authors are actively engaged in research involving the deployment of biologging devices on wild animals and have a professional interest in this field. Although they are committed to ethical standards and objective reporting, their involvement in this area may be perceived as a potential conflict of interest, which should be fully disclosed here for transparency.

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References

Altizer, S., Bartel, R., & Han, B. A. (2011). Animal migration and infectious disease risk. *Science, 331*(6015), 296–302. https://doi.org/10.1126/science.1194694

Andrews, R. D., Baird, R. W., Calambokidis, J., Goertz, C. E. C., Gulland, F. M. D., Heide-Jorgensen, M. P., Hooker, S. K., Johnson, M., Mate, B., Mitani, Y., Nowacek, D. P., Owen, K., Quakenbush, L. T., Raverty, S., Robbins, J., Schorr, G. S., Shpak, O. V., Townsend, F. I., Uhart, M., … Zerbini, A. N. T. (2019). Best practice guidelines for cetacean tagging. *Journal of Cetacean Research and Management, 20*(1), 27–66. https://doi.org/10.47536/jcrm.v20i1.237

Arrondo, E., & Pérez-García, J. M. (2025). Call for a critical review of widespread use of animal tracking devices. *European Journal of Wildlife Research, 71*(2), 27. https://doi.org/10.1007/s10344-025-01906-7

ASAB Ethical Committee/ABS Animal Care Committe. (2020). Guidelines for the treatment of animals in behavioural research and teaching. *Animal Behaviour, 159*, I–XI. https://doi.org/10.1016/j.anbehav.2019.11.002

Barron, D. G., Brawn, J. D., & Weatherhead, P. J. (2010). Meta-analysis of transmitter effects on avian behaviour and ecology. *Methods in Ecology and Evolution, 1*(2), 180–187. https://doi.org/10.1111/j.2041-210X.2010.00013.x

Beaulieu, M., & Masilkova, M. (2024). Plugging biologging into animal welfare: An opportunity for advancing wild animal welfare science. *Methods in Ecology and Evolution, 15*(12), 2172–2188. https://doi.org/10.1111/2041-210X.14441

Beltran, R. S., Kilpatrick, A. M., Picardi, S., Abrahms, B., Barrile, G. M., Oestreich, W. K., Smith, J. A., Czapanskiy, M. F., Favilla, A. B., Reisinger, R. R., Kendall-Bar, J. M., Payne, A. R., Savoca, M. S., Palance, D. G., Andrzejaczek, S., Shen, D. M., Adachi, T., Costa, D. P., Storm, N. A., , … Robinson, P. W. K. P., & Robinson, P. W. (2025). Maximizing biological insights from instruments attached to animals. *Trends in Ecology & Evolution, 40*(1), 37–46. https://doi.org/10.1016/j.tree.2024.09.009

Bengtsson, D., Safi, K., Avril, A., Fiedler, W., Wikelski, M., Gunnarsson, G., Elmberg, J., Tolf, C., Olsen, B., & Waldenström, J. (2016). Does influenza A virus infection affect movement behaviour during stopover in its wild reservoir host? *Royal Society Open Science, 3*(2), Article 150633. https://doi.org/10.1098/rsos.150633

Bidder, O. R., Arandjelović, O., Almutairi, F., Shepard, E. L. C., Lambertucci, S. A., Qasem, L. A., P, A., & Wilson, R. P. (2014). A risky business or a safe BET? A fuzzy set event tree for estimating hazard in biotelemetry studies. *Animal Behaviour, 93*, 143–150. https://doi.org/10.1016/j.anbehav.2014.04.025

Bograd, S., Block, B., Costa, D., & Godley, B. W. (2010). Biologging technologies: New tools for conservation. Introduction. *Endangered Species Research, 10*, 1–7. https://doi.org/10.3354/esr00269

Breed, D., Meyer, L. C. R., Steyl, J. C. A., Goddard, A., Burroughs, R., & Kohn, T. A. M. (2019). Conserving wildlife in a changing world: Understanding capture myopathy—a malignant outcome of stress during capture and translocation. *Conservation Physiology, 7*(1), Article coz027. https://doi.org/10.1093/conphys/coz027

Bridge, E. S., Thorup, K., Bowlin, M. S., Chilson, P. B., Diehl, R. H., Fléron, R. W., Hartl, P., Kays, R., Kelly, J. F., Robinson, W. D., & Wikelski, M. F. (2011). Technology on the move: Recent and forthcoming innovations for tracking migratory birds. *BioScience, 61*(9), 689–698. https://doi.org/10.1525/bio.2011.61.9.7

Casper, R. M. (2009). Guidelines for the instrumentation of wild birds and mammals. *Animal Behaviour, 78*(6), 1477–1483. https://doi.org/10.1016/j.anbehav.2009.09.023

Christensen, T., & Fantuzzi, J. (2024). External transmitter attachment in snakes: A systematic review of methods, efficacy, and impacts. *Animal Biotelemetry, 12*(1), 14. https://doi.org/10.1186/s40317-024-00371-4

Cooke, S. J., Hinch, S. G., Wikelski, M., Andrews, R. D., Kuchel, L. J., Wolcott, T. G., & Butler, P. J. (2004). Biotelemetry: A mechanistic approach to ecology. *Trends in Ecology & Evolution, 19*(6), 334–343. https://doi.org/10.1016/j.tree.2004.04.003

Costa-Pereira, R., Moll, R. J., Jesmer, B. R., & Jetz, W. S. (2022). Animal tracking moves community ecology: Opportunities and challenges. *Journal of Animal Ecology, 91*(7), 1334–1344. https://doi.org/10.1111/1365-2656.13698

Crofoot, M. C., Norton, T. M., Lessnau, R. G., Viner, T. C., Chen, T. C., Mazzaro, L. M., & Yabsley, M. J. (2009). Field anesthesia and health assessment of free-ranging Cebus capucinus in Panama. *International Journal of Primatology, 30*, 125–141. https://doi.org/10.1007/s10764-009-9333-6

Csada, R. D., James, P. C., & Espie, R. H. M. (1996). The "file drawer problem" of non-significant results: Does it apply to biological research? *Oikos, 76*(3), 591–593.

Cullen, J. A., Attias, N., Desbiez, A. L. J., & Valle, D. (2023). Biologging as an important tool to uncover behaviors of cryptic species: An analysis of giant armadillos (*Priodontes maximus*). *PeerJ, 11*, Article e14726. https://doi.org/10.7717/peerj.14726

EJournal of Animal Ecology. (2021). Updated animal ethics policy. *Animal Ecology in Focus*. https://animalecologyinfocus.com/2021/10/06/updated-animal-ethics-policy/. (Accessed 11 April 2025).

Elias, A. R., Golubovic, N., Krintz, C., & Wolski, R. (2017). *Where's the bear? Automating wildlife image processing using IoT and edge cloud systems. Proceedings of the Second International Conference on Internet-of-Things Design and Implementation*. https://doi.org/10.1145/3054977.3054986

Erichsen, S., & Hopla, C. E. (2021). History of the international council for laboratory animal science. *ILAR Journal, 62*(3), 369–406. https://doi.org/10.1093/ilar/ilac015

Fijn, R. C., van Bemmelen, R. S. A., Collier, M. P., Courtens, W., van Loon, E. E., Poot, M. J. M., & Shamoun-Baranes, J. (2024). Evaluation of tag attachment techniques for plunge-diving terns. *Ibis, 166*(3), 1003–1022. https://doi.org/10.1111/ibi.13306

Forni, M. (2007). Laboratory animal science: A resource to improve the quality of science. *Veterinary Research Communications, 31*(1), 43–47. https://doi.org/10.1007/s11259-007-0096-2

Hawkes, L. A., Fahlman, A., & Sato, K. (2021a). Introduction to the theme issue: Measuring physiology in free-living animals. *Philosophical Transactions of the Royal Society B: Biological Sciences, 376*(1830), Article 20200210. https://doi.org/10.1098/rstb.2020.0210

Hawkes, L. A., Fahlman, A., & Sato, K. (2021b). What is physiologging? Introduction to the theme issue, part 2. *Philosophical Transactions of the Royal Society B: Biological Sciences, 376*(1831), Article 20210028. https://doi.org/10.1098/rstb.2021.0028

Hotopp, I., Dreesmann, L. K., & Becker, N. (2022). Habitat and season effects on small mammal bycatch in live trapping. *Biology, 11*(12), Article 18106. https://doi.org/10.3390/biology11121806

Houstin, A., Zitterbart, D. P., Winterl, A., Richter, S., Planas-Bielsa, V., Chevallier, D., Ancel, A., Fournier, J., Fabry, B., & Le Bohec, C. (2022). Biologging of emperor penguins—Attachment techniques and associated deployment performance. *PLoS One, 17*(8), Article e0265849. https://doi.org/10.1371/journal.pone.0265849

Jetz, W., Tertitski, G., Kays, R., Mueller, U., Wikelski, M., & Supporting authors. (2022). Biological Earth observation with animal sensors. *Trends in Ecology & Evolution, 37*(4), 293–298. https://doi.org/10.1016/j.tree.2021.11.011

Joo, R., Picardi, S., Boone, M. E., Clay, T. A., Patrick, S. C., Romero-Romero, V. S., & Basille, M. (2022). Recent trends in movement ecology of animals and human mobility. *Movement Ecology, 10*(1), 26. https://doi.org/10.1186/s40462-022-00322-9

Kang, M., Long, T., Chang, C., Meng, T., Ma, H., Li, Z., Li, P., & Chen, Y. (2022). A review of the ethical use of animals in functional experimental research in China based on the "Four R" principles of reduction, replacement, refinement, and responsibility. *Medical Science Monitor, 28*, Article e938807. https://doi.org/10.12659/MSM.938807

Kay, W. P., Naumann, D. S., Bowen, H. J., Withers, S. J., Evans, B. J., Wilson, R. P., Stringell, T. B., Bull, J. C., Hopkins, P. W., & Börger, L. M. (2019). Minimizing the impact of biologging devices: Using computational fluid dynamics for optimizing tag design and positioning. *Methods in Ecology and Evolution, 10*(8), 1222–1233. https://doi.org/10.1111/2041-210X.13216

Kays, R., & Wikelski, M. (2023). The internet of animals: What it is, what it could be. *Trends in Ecology & Evolution, 38*(9), 859–869. https://doi.org/10.1016/j.tree.2023.04.007

Kelly, C. D. (2019). Rate and success of study replication in ecology and evolution. *PeerJ, 7*, Article e7654. https://doi.org/10.7717/peerj.7654

Kohrt, F., Smaldino, P. E., McElreath, R., & Schönbrodt, F. (2023). Replication of the natural selection of bad science. *Royal Society Open Science, 10*(2), Article 221306. https://doi.org/10.1098/rsos.221306

Kyte, A., Pass, C., Pemberton, R., Sharman, M., & McKnight, J. C. (2019). A computational fluid dynamics (CFD) based method for assessing the hydrodynamic impact of animal-borne data loggers on host marine mammals. *Marine Mammal Science, 35*(2), 364–394. https://doi.org/10.1111/mms.12540

Lameris, T. K., & Kleyheeg, E. (2017). Reduction in adverse effects of tracking devices on waterfowl requires better measuring and reporting. *Animal Biotelemetry, 5*(1), 24. https://doi.org/10.1186/s40317-017-0139-6

Lameris, T. K., Müskens, G. J. D. M., Kölzsch, A., Dokter, A. M., Van der Jeugd, H. P., & Nolet, B. A. (2018). Effects of harness-attached tracking devices on survival, migration, and reproduction in three species of migratory waterfowl. *Animal Biotelemetry, 6*(1), 7. https://doi.org/10.1186/s40317-018-0153-3

Lindsjö, J., Fahlman, Å., & Törnqvist, E. (2016). Animal welfare from mouse to moose—Implementing the principles of the 3Rs in wildlife research. *Journal of Wildlife Diseases, 52*(2), S65–S77. https://doi.org/10.7589/52.2S.S65

Longarini, A., Duriez, O., Shepard, E., Safi, K., Wikelski, M., & Scacco, M. (2023). Effect of harness design for tag attachment on the flight performance of five soaring species. *Movement Ecology, 11*(1), 39. https://doi.org/10.1186/s40462-023-00408-y

MacCallum, C. J. (2010). Reporting animal studies: Good science and a duty of care. *PLoS Biology, 8*(6), Article e1000413. https://doi.org/10.1371/journal.pbio.1000413

Meierhofer, M. B., Ratcliffe, J. M., & Faure, P. A. (2024). Re-weighing the 5% tagging recommendation: Assessing the potential impacts of tags on the behaviour and body condition of bats. *Mammal Review, 55*(3). https://doi.org/10.1111/mam.12369

Mizrahy-Rewald, O., Winkler, N., Amann, F., Neugebauer, K., Voelkl, B., Grogger, H. A., Ruf, T., & Fritz, J. (2023). The impact of shape and attachment position of biologging devices in Northern Bald Ibises. *Animal Biotelemetry, 11*(1), 8. https://doi.org/10.1186/s40317-023-00322-5

Morelle, K., Besnard, A. J., & Le Gall-Reculé, C. (2023). Accelerometer-based detection of African swine fever infection in wild boar. *Proceedings of the Royal Society B: Biological Sciences, 290*(2005), Article 20231396. https://doi.org/10.1098/rspb.2023.1396

Nakagawa, S., Lagisz, M., Yang, Y., & Drobniak, S. M. (2024). Finding the right power balance: Better study design and collaboration can reduce dependence on statistical power. *PLoS Biology, 22*(1), Article e3002423. https://doi.org/10.1371/journal.pbio.3002423

Nathan, R., Getz, W. M., Revilla, E., Holyoak, M., Kadmon, R., Saltz, D., & Smouse, P. E. (2008). A movement ecology paradigm for unifying organismal movement research. *Proceedings of the National Academy of Sciences of the United States of America, 105*(49), 19052–19059. https://doi.org/10.1073/pnas.0800375105

Nosek, B. A., Ebersole, C. R., DeHaven, A. C., & Mellor, D. T. J. (2018). The preregistration revolution. *Proceedings of the National Academy of Sciences of the United States of America, 115*(11), 2600–2606. https://doi.org/10.1073/pnas.1708274114

Palmer, A., & Greenhough, B. (2021). Out of the laboratory, into the field: Perspectives on social, ethical and regulatory challenges in UK wildlife research. *Philosophical Transactions of the Royal Society B: Biological Sciences, 376*(1831), Article 20200226. https://doi.org/10.1098/rstb.2020.0226

Parker, M. O., & McElligott, A. G. (2023). Ethical evolutions: Navigating the future of animal behaviour and welfare research. *Research Ethics, 19*(4), 369–372. https://doi.org/10.1177/17470161231202299

Payne, A., Hale, C., Kendall-Bar, J., & Beltran, R. (2024). Minimum reporting standards can promote animal welfare and data quality in biologging research. *EcoEvoRxiv*. https://doi.org/10.32942/X29K7X

Percie du Sert, N., Hurst, V., Ahluwalia, A., Alam, S., Avey, M. T., Baker, M., Browne, W. J., Clark, A., Cuthill, I. C., Dirnagl, U., Emerson, M., Garner, P., Holgate, S. T., Howells, D. W., Karp, N. A., Lazic, S. E., Lidster, K., MacCallum, C. J., Macleod, M., … Würbel, H. (2020). The ARRIVE guidelines 2.0: Updated guidelines for reporting animal research. *BMC Veterinary Research, 16*(1), 242. https://doi.org/10.1186/s12917-020-02451-y

Petkov, C. I., Flecknell, P., Murphy, K., Basso, M. A., Mitchell, A. S., Hartig, R., & Thompson-Iritani, S. G. (2022). Unified ethical principles and an animal research 'Helsinki' declaration as foundations for international collaboration.

Current Research in Neurobiology, 3, Article 100060. https://doi.org/10.1016/j.crneur.2022.100060

Portugal, S. J., & White, C. R. (2018). Miniaturization of biologgers is not alleviating the 5% rule. *Methods in Ecology and Evolution, 9*(7), 1662–1666. https://doi.org/10.1111/2041-210X.13013

Portugal, S. J., & White, C. R. (2022). Externally attached biologgers cause compensatory body mass loss in birds. *Methods in Ecology and Evolution, 13*(2), 294–302. https://doi.org/10.1111/2041-210X.13754

Rattenborg, N. C., Voirin, B., Cruz, S. M., Tisdale, R., Dell'Omo, G., Lipp, H. P., Wikelski, M., & Vyssotski, A. L. (2016). Evidence that birds sleep in mid-flight. *Nature Communications, 7*, Article 12468. https://doi.org/10.1038/ncomms12468

Richter, S. H., Caspers, B. A., Dammhahn, M., & Kaiser, S. J. (2025). Animal research revisited – The case of behavioural studies. *Trends in Ecology & Evolution, 40*(2), 99–103. https://doi.org/10.1016/j.tree.2024.11.014

Ropert-Coudert, Y., & Wilson, R. P. (2005). Trends and perspectives in animal-attached remote sensing. *Frontiers in Ecology and the Environment, 3*(8), 437–444. https://doi.org/10.1890/1540-9295(2005)003[0437:TAPIAR]2.0.CO;2

Ropert-Coudert, Y., Wilson, R. P., & Cooke, S. J. (2009). Diving into the world of biologging. *Endangered Species Research, 10*, 21–27. https://doi.org/10.3354/esr00188

Rutz, C. (2022). Register animal-tracking tags to boost conservation. *Nature, 609*(7926), 221. https://doi.org/10.1038/d41586-022-02821-6

Smaldino, P. E., & McElreath, R. (2016). The natural selection of bad science. *Royal Society Open Science, 3*(9), Article 160384. https://doi.org/10.1098/rsos.160384

Smaldino, P. E., Turner, M. A., & Contreras Kallens, P. A. (2019). Open science and modified funding lotteries can impede the natural selection of bad science. *Royal Society Open Science, 6*(7), Article 190194. https://doi.org/10.1098/rsos.190194

Smith, A. J., Clutton, R. E., Lilley, E., Hansen, K. E. A., & Brattelid, T. (2018). PREPARE: Guidelines for planning animal research and testing. *Laboratory Animals, 52*(2), 135–141. https://doi.org/10.1177/0023677217724823

Soulsbury, C. D., Gray, H. E., Smith, L. M., Braithwaite, V., Cotter, S. C., Elwood, R. W., Wilkinson, A., & Collins, L. M. (2020). The welfare and ethics of research involving wild animals: A primer. *Methods in Ecology and Evolution, 11*(10), 1164–1181. https://doi.org/10.1111/2041-210X.13435

Stewart, A. J., & Plotkin, J. B. (2021). The natural selection of good science. *Nature Human Behaviour, 5*(11), 1510–1518. https://doi.org/10.1038/s41562-021-01153-3

Tucker, M. A., Böhning-Gaese, K., Fagan, W. F., Fryxell, J. M., Van Moorter, B., Alberts, S. C., Ali, A. H., Allen, A. M., Attias, N., Avgar, T., Bartlam-Brooks, H., Bayarbaatar, B., Belant, J. L., Bertassoni, A., Beyer, D. E., Bidner, L., van Beest, F. M., Blake, S., Blaum, N., , … Mueller, T., & Bartlam-Brooks, H. (2018). Moving in the Anthropocene: Global reductions in terrestrial mammalian movements. *Science, 359*(6374), 466–469. https://doi.org/10.1126/science.aam9712

Vyssotski, A. L., Serkov, A. N., Dell'Omo, G., Dell'Ariccia, G., Abramchuk, A. N., Serkov, A. N., Latanov, A. V., Loizzo, A., Wolfer, D. P., & Lipp, H.-P. (2009). EEG responses to visual landmarks in flying pigeons. *Current Biology, 19*(14), 1159–1166. https://doi.org/10.1016/j.cub.2009.05.070

Wikelski, M., Kays, R. W., Kasdin, N. J., Thorup, K., Smith, J. A., & Swenson, G. W. (2007). Going wild: What a global small-animal tracking system could do for experimental biologists. *Journal of Experimental Biology, 210*(2), 181–186. https://doi.org/10.1242/jeb.02629

Wikelski, M., Quetting, M., Bates, J., Berger-Wolf, T., Bohrer, G., Börger, L., Chapple, T., Crofoot, M. C., Davidson, S. C., Dechmann, D. K. N., Ellis-Soto, D., Ellwood, E. R., Fiedler, W., Flack, A., Fruth, B., Franconi, N., Havmøller, R. W., Hirt, J., Hussey, N. E., … Kays, R. (2024). Introducing a unique animal ID and digital life history museum for wildlife metadata. *Methods in Ecology and Evolution, 15*(10), 1777–1788. https://doi.org/10.1111/2041-210X.14407

Wild, T. A., van Schalkwyk, L., Viljoen, P., Heine, G., Richter, N., Vorneweg, B., Koblitz, J. C., Dechmann, D. K. N., Rogers, W., Partecke, J., Linek, N., Volkmer, T., Gregersen, T., Havmøller, R. W., Morelle, K., Daim, A., Wiesner, M., Wolter, K., Fiedler, W., … Wikelski, M. W. (2023). A multi-species evaluation of digital wildlife monitoring using the Sigfox IoT network. *Animal Biotelemetry, 11*(1), 13. https://doi.org/10.1186/s40317-023-00326-1

Williams, H. J., Taylor, L. A., Benhamou, S., Bijleveld, A. I., Clay, T. A., de Grissac, S., Demšar, U., English, H. M., Franconi, N., Gómez-Laich, A., Griffiths, R. C., Kay, W. P., Morales, J. M., Potts, J. R., Rogerson, K. F., Rutz, C., Spelt, A., Trevail, A. M., Wilson, R. P., & Börger, L. (2020). Optimizing the use of biologgers for movement ecology research. *Journal of Animal Ecology, 89*(1), 186–206. https://doi.org/10.1111/1365-2656.13094

Wilmers, C. C., Nickel, B., Bryce, C. M., Smith, J. A., Wheat, R. E., & Yovovich, V. (2015). The golden age of bio-logging: How animal-borne sensors are advancing the frontiers of ecology. *Ecology, 96*(7), 1741–1753. https://doi.org/10.1890/14-1401.1

Wilson, R. P., & McMahon, C. R. (2006). Measuring devices on wild animals: What constitutes acceptable practice? *Frontiers in Ecology and the Environment, 4*(3), 147–154. https://doi.org/10.1890/1540-9295(2006)004[0147:MDOWAW]2.0.CO;2

Wilson, R. P., Rose, K. A., & Wikelski, M. (2021). Animal lifestyle affects acceptable mass limits for attached tags. *Proceedings of the Royal Society B: Biological Sciences, 288*(1961), Article 20212005. https://doi.org/10.1098/rspb.2021.2005

Wilson, A. D. M., Wikelski, M., Wilson, R. P., & Cooke, S. J. (2015). Utility of biological sensor tags in animal conservation. *Conservation Biology, 29*(4), 1065–1075. https://doi.org/10.1111/cobi.12486

Yanco, S. W., Costa, D. P., Robinson, P. W., & Beltran, R. S. (2024). Tracking individual animals can reveal the mechanisms of species loss. *Trends in Ecology & Evolution, 40*(1), 47–56. https://doi.org/10.1016/j.tree.2024.09.008

Yang, Y., van Zwet, E., Ignatiadis, N., & Nakagawa, S. (2024). A large-scale in silico replication of ecological and evolutionary studies. *Nature Ecology & Evolution, 8*(12), 2179–2183. https://doi.org/10.1038/s41559-024-02530-5

Zou, C. X., Becker, J. E., Phillips, A. T., Garritano, J. M., Krumholz, H. M., Miller, J. E., & Ross, J. S. (2018). Registration, results reporting, and publication bias of clinical trials supporting FDA approval of neuropsychiatric drugs before and after FDAAA: A retrospective cohort study. *Trials, 19*(1), 581. https://doi.org/10.1186/s13063-018-2957-0