The burden of a failed error culture in biologging

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Abstract

Driven by technological advancements and reduced costs, biologging has seen a rapid growth transforming the study of animal behaviour and ecology. This "golden era" of animal tracking provides unprecedented insights into wildlife, aiding conservation efforts and ecological research. However, in the wake of the rapid growth loom pressing ethical and methodological challenges, including a lack of error reporting, inconsistent standards, and insufficient consideration of animal welfare. Here we highlight the urgent need for a robust error culture in biologging to address these issues. We propose four key directions for action: (1) establishing a biologging expert registry to enhance collaboration and knowledge sharing; (2) implementing pre-registration as well as post-reporting 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 programs and ethical guidelines tailored to the unique challenges of biologging research. By continuing a more rigorous implementation of a 5R principle —Replace, Reduce, Refine, Responsibility, and Reuse (data)— alongside these initiatives, 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.

Introduction

The field of animal bio-telemetry and more generally biologging is growing at an unprecedented rate (Bridge et al., 2011; Wilmers et al., 2015; Ropert-Coudert and R. P. Wilson, 2005). Increasing numbers of animals are equipped with electronic devices, resulting in soaring data volumes and publications (Joo et al., 2022). This success is clearly technology-driven, amplified by plummeting prices for devices and a thriving diversity of commercial and academic suppliers (Cooke et al., 2004). The miniaturization of electronic sensors, increased battery capacities, and lower energy consumption permit smaller, cheaper, and longer-lived devices (Ropert-Coudert and R. P. Wilson, 2005). Technological innovation extends to data transmission networks, from GSM/GPRS and IoT to global satellite-based communication networks, allowing data reception from anywhere, anytime (Elias et al., 2017; Wild et al., 2023). Engineers' creativity is further fuelled by a continuous supply of novel sensors that can be added to devices deployed on animals, opening up new avenues of research (Wilmers et al., 2015). This serendipitous alignment of circumstances has created a field full of opportunities, accelerating scientific discoveries and giving rise to what is termed the “golden era" of biologging (Wilmers et al., 2015). The transformative power provided by the ubiquity and affordability of biologging devices seems boundless, offering increasing options for using better technology at lower costs (R. Kays and Wikelski, 2023). While it almost seems that whatever researchers touch in the field of tech-driven ecological field research turns into gold, we believe that as a community, the time is ripe to question and reflect on how this rapid growth and development can –and should– be achieved sustainably and ethically (Soulsbury et al., 2020; R. P. Wilson and McMahon, 2006).

The Rise of Biologging

Ultimately, the necessity of studying animal movement stems from movement being a defining attribute of life itself. What was originally a niche research field has now arrived in the mainstream (Cooke et al., 2004; R. Kays and Wikelski, 2023; Wikelski, R. W. Kays, et al., 2007). From today’s perspective, we cannot fully appreciate the enormous effort and stamina of research pioneers to never give up on the seemingly impossible task of studying individual wild animals in their natural habitat (Clutton-Brock and Sheldon, 2010; Macnab, 1983; Romesburg, 1981). Biologging devices provide invaluable and irreplaceable knowledge in animal behaviour, ecology, conservation biology, and disease ecology, among others (A. Wilson et al., 2015; Costa-Pereira et al., 2022; Wikelski, R. W. Kays, et al., 2007; Beltran et al., 2025). Many aspects of biologging research directly relate to global change and the challenges that growing human impact poses to nature and people (Tucker et al., 2018). Without biologging, our ability to protect species in their natural habitat would be severely impaired (A. Wilson et al., 2015). Data collected through biologging are not only used for purely scientific purposes, they serve to inform decision-makers, decide on the placement of conservation areas, and are a corner stone in monitoring and documenting change and mitigating human-wildlife conflicts, among others (A. Wilson et al., 2015; Morelle et al., 2023; Altizer, Bartel, and Han, 2011; Bengtsson et al., 2016). Biologging is the most effective tool in avoiding animal death, providing informing on mechanisms leading to population decline (Yanco et al., 2024; Jetz et al., 2022; Tucker et al., 2018). Addressing these topics requires understanding how and why animals move, studying behaviour in the wild, and interactions with their biotic and abiotic environments (Nathan et al., 2008). Biologging devices both document and provide unprecedented insights into the behavioural heritage of the natural world. They link us, and particularly the public, more closely to our living planet where irrespective of affordability, people can appreciate the importance of ecological and natural phenomena and the impact that animals and their behaviours have on us humans (Yanco et al., 2024; Jetz et al., 2022).

The Dark Side of Progress

Rapid technological development and miniaturization of bio-loggers has made studying more species and individuals in myriad ecological landscapes possible (Beltran et al., 2025). 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 varying amount of acquired previous experience (personal or learned via word-of-mouth). Largely, decision and advancements are based on trial and error. This is a consequence of scientists pioneering new research avenues using novel technology on previously never-tagged species.

Increasingly critical voices are highlighting the ethical and environmental impacts of biologging (Portugal and White, 2022; Longarini et al., 2023; Casper, 2009; R. P. Wilson and McMahon, 2006; Soulsbury et al., 2020; Payne et al., 2024). Since biologging inherently relies on the use of animals to obtain data, ethical considerations must be a core element of the field (Parker and 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 publication (Arrondo and Pérez-García, 2025) calling for a critical review of biologging devices' widespread use notes that a majority of animals equipped with biologging devices never contributed to scientific publications, leading to trivializing of the use of biologging devices and the associated burden on animals. This argument overlooks the potential benefits of biologging in important aspects such as monitoring and management. Ultimately it is futile to try to turn back time on the fact that the technology has long, and irreversibly, become mainstream. Arrondo and Pérez-García 2025 emphasize, however, 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? Previous calls for a critical view on animal use and biologging in research mainly aim to refine aspects directly pertaining to the animals' welfare. This is achieved by focusing on the ethical approval process and/or calling for a valuing system where a putative outcome toward the researcher is weighed by an amount of imposed burden (Arrondo and Pérez-García, 2025). In addition, the implementation of a 3Rs principle, which is aimed to improve animal welfare and research quality, has been slower in wildlife research compared to its laboratory counterpart (Lindsjö, Fahlman, and Törnqvist, 2016). This is likely due to a mismatch between the controlled lab conditions that the 3Rs as framework were proposed for, and the inherent complexity of working in the wild. Extending existing principles to a 5R principle specific to the area of wildlife research using biologging can clearly help reduce animal burden (Box 1).

Box 1: The 5R Principle in Biologging

- **Replace**: Assess if biologging using animals is essential for answering research questions. Prioritize using 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.
- **Reduce**: Minimize animal use by advancing technology, setting device standards, and improving data collection efficiency. Clearly articulate hypotheses and verify methods to use only the necessary number of animals.
- **Refine**: Lower burden on animals by improving device technology and wearability/comfort and enhancing deployment expertise among researchers.
- **Responsibility**: Establish, and uphold ethical accountability throughout research, prioritizing animal welfare and adhering to institutionalised ethical standards.
- **Reuse**: Emphasize data reuse to improve reproducibility, reduce animal burden, and accelerate scientific discovery.

Box 1: The 5R principle for biologging as an extension to the 4R principle with the aim to reduce the number of animals used and burdened in wildlife research.

Beyond these important considerations, and despite the pervasiveness of biologging in so many aspects of studying animals in the wild, the near-absence of a reporting and error culture is striking. While journals and societies are increasingly more rigorous about the declaration of ethical approvals and publishing detailed description of methodology, failures are neither publicly documented, nor requested to be reported (Animal Behaviour, 2020; Ecology, 2021). This focus on success publishing leads to a “file drawer effect" (Csada, James, and Espie, 1996). Failures, when shared and learned from, can increase the return on investment of research –both financially and intellectually. They should be considered an indispensable cornerstone in (wild) animal welfare and research more generally.

We would like to address the lack of error and reporting culture, highlighting three areas in serious need of consideration:

- animal welfare, which is the main focus of the above mentioned critical voices raised hitherto,
- technology, which rarely has been part of a discourse involving how its affecting the impact of studying animals in the wild,
- and the human aspect, the largely neglected foundational element in animal welfare.

Based on a non-representative and personal assessment of the status-quo in these three areas, we would like to propose four action items that could tackle the challenges of a sustainable and ethical growth of the biologging field.

Animals and their welfare

All biologging researchers are more or less intimately familiar with aspects of the dark side of our work, as we have injured or lost animals and/or know of colleagues who have. Yet reports or publications of failure very rarely surface in the field against all odds (but see Crofoot et al., 2009; Houstin et al., 2022; Fijn et al., 2024). Mostly it is through hearsay or because we have witnessed the loss or harm to animals ourselves. Clearly, everyone’s top priority in the field is and should be the welfare of their study animals. But owing to the trial and error based nature of acquiring experience and improving procedures, combined with the lack of transparent reporting of negative experiences in publications and communication between different researchers, mistakes are made due to ‘ ‘reinventions of the wheel’ ’. While mistakes do happen and lessons are being learned, we as a community are not invoking our full potential due to reluctance to openly share our experiences, or even seriously demand for, and engage in, systematic reporting. How many mistakes could have been prevented if the field had fostered a transparent error culture —one where systematic reporting gave everyone access to crucial data and real objective opportunities to learn (Christensen and Fantuzzi, 2024; Lameris and Kleyheeg, 2017; Payne et al., 2024; MacCallum, 2010)?

Occasionally, animals succumb to handling stress,– referred to as *capture myopathy*– a diagnosis essentially for a malignant outcome of stress through handling (animals) with a lethal outcome (Breed et al., 2019). Given the existence of a diagnostic term for death by handling, we should accept that, as researchers, we impact our study animals through capture and deployment of biologging devices. We should do whatever we can to reduce our impact, for the sake of the individual animals' welfare, since we have a moral obligation towards that individual being (Soulsbury et al., 2020; Petkov et al., 2022) but also to minimize the bias on the very data we set out to collect. It is crucial that estimates of the impact of biologging devices consider the full lifestyle of the animal: for example, in cheetahs it was found that while 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 (R. P. Wilson, Rose, et al., 2021). A lack of consideration of the impact of biologging devices on all aspects of an animal' s behaviour thus both lead to harm and discomfort for the animal, as well as limit the generalizability and reproducibility of findings because the device itself altered or hindered the animal's normal lifestyle and social interactions. A further consideration would be to consider the impacts of biologging on non-research-target individuals and species– whether through trap by-catch (Hotopp et al., 2022) or the 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 quite substantially large proportion of the devices we deploy on animals will *never deliver actual data.* While researchers embark on expensive expeditions, work under sometimes dangerous conditions to catch and equip animals with impactful devices, not seldom these devices yield little or much less required data than needed to answer the scientific questions. There are endless intangible stories of epic tech failure that are shared orally among researchers, about 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, and animals getting trapped in their own biologging attachments (just to name a few). These device failures mark a unnecessary harm to the animals and a complete loss and waste of research efforts. Knowledge about such incidences is passed on informally, when colleagues discuss prior experiences with a certain device or manufacturer during after-hour exchanges in conferences or symposia. Because of the expected, and unpredictable, device failures, experienced field biologists usually include tests for device functionality prior to deployment, trying to minimize the failure rate of devices deployed on animals. For years, and still to this day, we think, biologging devices had and have to be considered experimental electronic devices with no liability or guarantee to work as advertised regardless of the promises of the vendors. There simply is no objective, independent and quantitative method to predict how well devices will perform. The diverse companies and workshops catering to biologging, rapid development cycles, varied deployment conditions and taxa, and field biologists' input create a noisy backdrop that makes it nearly impossible to objectively assess device reliability and acceptable failure rates. Most commercial suppliers are small or medium-sized businesses– if not outright tinkering booths or garage-based enterprises often spinning off research institutions. They simply have limited capacities to invest in systematic tests and standardisation. Although some companies refund the price of failing tags, there is no recompensation of the expenses that a failed expedition entails, which is usually much higher than the mere cost of the failing tech. Additionally, there is no way to compensate the animals burdened with dead weight or the environment for the pollution of electronic waste. This effect is even more critical when the failed technology results in causing more harm to animals than anticipated. For example, when the drop-off mechanism of a collar fails, additional capture and handling of the animal is often required to manually remove the device. The worst outcome of failing technology can include sacrificing animals to prevent further suffering (see e.g. `https://www.swissinfo.ch/eng/sci-tech/deer-study-goes-awry/36812992`).

The human aspect

Surely, with the development of ever more sophisticated devices, there has been a steep learning curve. In the time preceding the wide availability of commercial collars, we had to often rely on Do-It-

Yourself and experimental engineering to push the boundaries. We were, are, and will continue to be, in uncharted territories– trying, failing, and learning from our mistakes. However, as the field of tech-driven animal research matures and grows, it is time to reflect on how the biologging community can initiate a more systemic and systematic approach to error culture when it comes to the knowledge and state-of-the-art in attaching tech to animals. All of us so far went through arcane biologging apprenticeships to acquire the art and skill of attaching devices to animals. Of course we did all we could to learn from mentors (and not seldom trying to reconcile often diametrically opposing strong opinions of seasoned experts). We read published papers and methods, and acquired individually field experience over years of learning from our individual mistakes. As a consequence, we all vary in the ways we do field work, a variation that could represent a fertile ground for evolving better procedures and improve, if only we would have a reproducible and quantitative approach to speaking about the art of handling animals and making wildlife wearables better.

Towards a (better) Error Culture

Studying animals using biologging technology is indispensable and will continue to grow in its use. However, we can not, and should not, ignore the dark side. No one is in a better position to improve the situation than the biologging community itself. If we do not attempt improvements, one day rules and regulatory measures might be imposed both formally, through legal means, and informally through public admonishment– and not necessarily driven by optimizing the balance between welfare and research necessity. Our freedom in what we do comes with a responsibility which we must begin to shoulder more seriously.

Four action items

As a community we still must acknowledge untapped potential for improvement: the endorsement of an error culture that holistically improves our research by establishing better communication and exchange tools to maximize our ability to improve (Figure 1).

We acknowledge that publishing our failures, or even an external auditing procedure in case of failures, are unlikely or infeasible to implement in the short run, albeit in the interest of our field's progress.

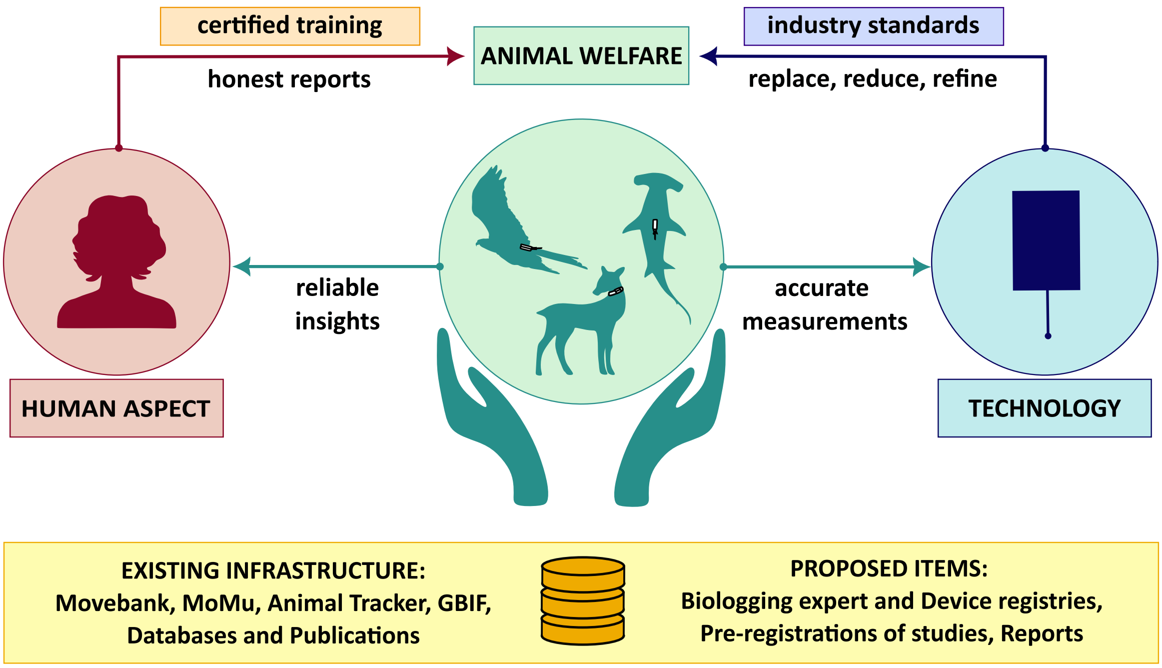

Figure 1: A suggested comprehensive approach to ethical and effective animal biologging practices, emphasizing animal welfare as the central priority. Harmonious integration of human expertise and technological advancements can enhance animal welfare while collecting valuable telemetry data. Specifically, a biologging expert should be equipped with certified continuous training and committed to transparent and systematic reporting. Tag devices should meet industrial standards and be continuously improved. The combination of the human and technology aspects alleviates the burden on animals and provides reliable insights crucial for 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 pre-registration of studies and complete reports. Colour coding used throughout this and subsequent figures is the following: green is 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.

However, we suggest clear improvements to the current DADT (don't ask, don't tell), "elephant in the room" status-quo.

For one, a *biologging experts registry* could be a major step (Figure 2), which combined with, second, a request for pre-registration, results reporting, and publication bias reporting (Figure 3) would clearly enhance our knowledge pool and allow us to overcome the current 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 navigate a path towards avoiding to commit to more failures (see also the fourth proposal). A third pivotal action item is a demand for industry standards from device manufacturers (Figure 4). Fourth, and finally, we need to conceive an educational and training programme tailored to the demands and required skills that biologging specifically poses towards the researchers, including how we collaborate and interact (Figure 5). That 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.

1. A Biologging Expert Registry

One immediately feasible option that could improve communication in our large and growing community would be a registry of biologging experts (Figure 2). This could be cross-linked to various existing or emerging repositories and databases through individual identifiers like ORCID and linkage to a biologging device registry. Such a registry could serve as a point of contact for other researchers and as a reference for ethics committees. It could help propagate relevant information efficiently and provide ethical and legal entities 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 (BLS), the Animal Behavior Society (ABS), or the Association for the Study of Animal Behaviour (ASAB). Less practically, it could be internationally linked but independently managed by national entities. The registry could archive relevant information about biologists and veterinarians conducting biologging research and their field of expertise (species, tagging methods, devices experience etc.). Taking in consideration 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, harnesses).

Pertaining to international field work, such a linked registry could help to identify relevant experts across national boundaries and different regulation schemes. This registry would inform about the type of field actions and methods such as capture, handling, marking, invasive and non-invasive technology and attachment methods, anaesthesia, and experience with working in specific field sites that they have worked at. This registry could be linked to the tag/device registry (Rutz, 2022) allowing us to know who has used which kinds of hardware, their experience with it and their interaction with the producing companies. Likewise, the unique animal identifiers of handled animals could be cross-referenced (Wikelski, Quetting, et al., 2024), allowing researchers to follow up on events associated with these animals including the roles that bio-loggers played in their lives. Naturally, the registry would also 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 listing publications or referencing ORCID-iDs), including re-use of data they contributed to by consortial and comparative initiatives increasing visibility and ownership beyond the role of co-authorship. This would require the registry to accommodate adding publications to the profiles as data contributors or involvements other than author roles, for example technical assistance, paid assistance and other forms of contribution to animal based studies.

2. Pre-registration 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 request a change in procedures to penetrate the field quickly. This is similar to the “file drawer effect", (Csada, James, and Espie, 1996) where a bias towards desired outcomes leads to a publication of false positives and faulty science (Smaldino and McElreath, 2016). However in this case, the negative externality is the welfare of animal research subjects as well as the well-being and time of researchers. Since new biologging studies tend to follow published methodologies, it is almost inevitable that positive reporting bias will manifest in suboptimal, or even outright detrimental, procedures for a long time despite better knowledge existing. It will also be very hard to impossible to purge knowledge deemed or proven as detrimental from the knowledge

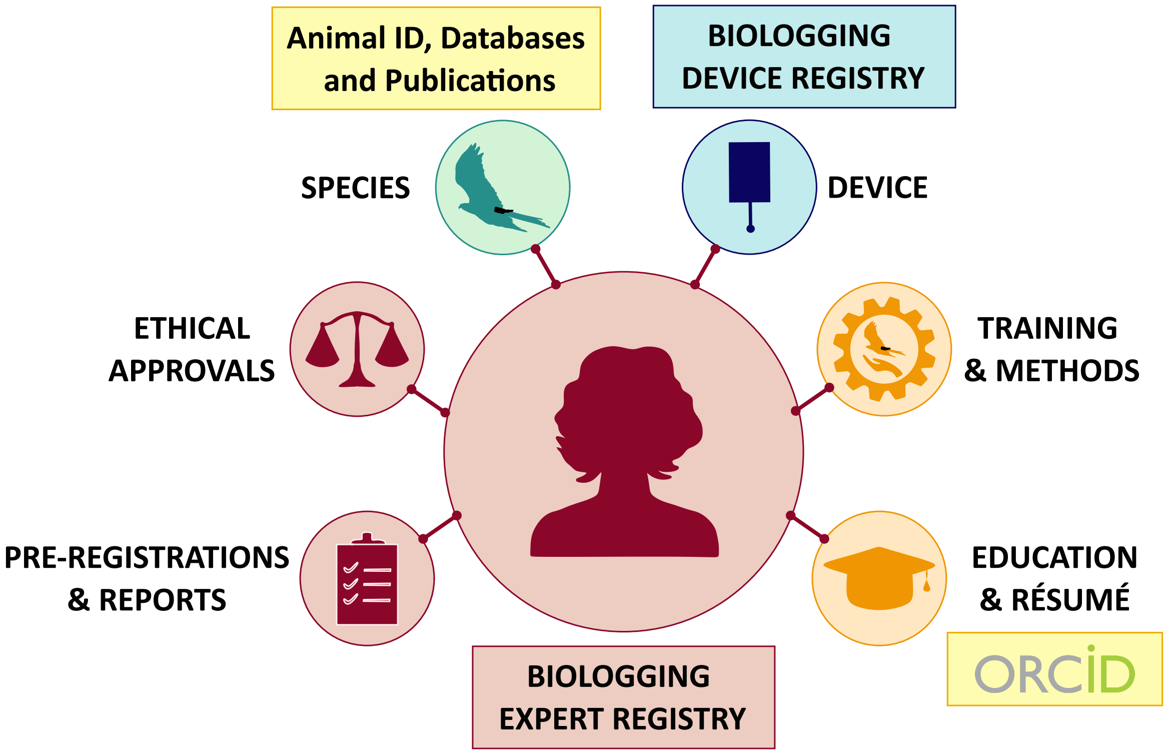

Figure 2: Suggestion for a potential biologging expert registry. Each expert's profile includes their personal information, such as education path, résumé/CV, and ORCID profile. Each expert's experience with study species and tags is documented, with links to the proposed tag/device registry, along with 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 pre-registrations of animal studies, transparent reports, and the associated ethical approvals and 3. aims to facilitate communication and feedback within the global biologging community.

base. The publication bias against negative results also means that experiments and procedures get repeated many times with no prospect of success.

As with the file drawer effect, the only solution is collective action and institutional change (Smaldino and McElreath, 2016; Kohrt et al., 2023). We should aim to move from copying historic and possibly highly problematic yet published methodologies to a system that follows the most recent quantitative and peer reviewed assessment of procedures. Furthermore, we should continue to systematically question what we do and how we do things, instead of just following the trodden paths of days past (Figure 3). We strongly believe that we should adopt a reporting system that allows us to record and assess negative results. The need for standardised and systematic data reporting is beyond question. With the advent of large language models, there are new possibilities for quantitative analysis of narrative reports, which could provide a tremendous opportunity for little structured publications of field reports and notes. Storing narratives about field events from capture over handling to deployment, even including images and videos of tech and all the circumstantial experiences when attaching devices to animals, however irrelevant and small they might have seem at the time, could be summarized and quantified efficiently, across languages and media.

One of the fundamental steps taken to improve drug discovery clearly is the FDA imposed registration, results reporting, and publication bias of clinical trials (FDAAA: The Food and Drug Administration Amendments Act, Zou et al., 2018). Introducing this measure led to a marked improvement in virtually all aspects of drug discovery improving the ratio between trials and successful discoveries saving money and leading to better treatments. Likewise a pre-registration of biologging devices (for example for GPS position logging devices in combination with the suggested tag-registry) requiring researchers to published the intended use of biologging devices on animals would provide the opportunity for the relevant researchers to communicate and possibly collaborate. A mandate on following up on the pre-registered devices after deployment would allow to improve performance by quantitatively assessing success to failure ratio. We would also learn about the bias that is introduced by failing to publish negative results. Such a registry could also actively suggest links based on the pre-registered technology use, targeted taxa, attachment methods and possibly more metadata without disclosing any of the raw

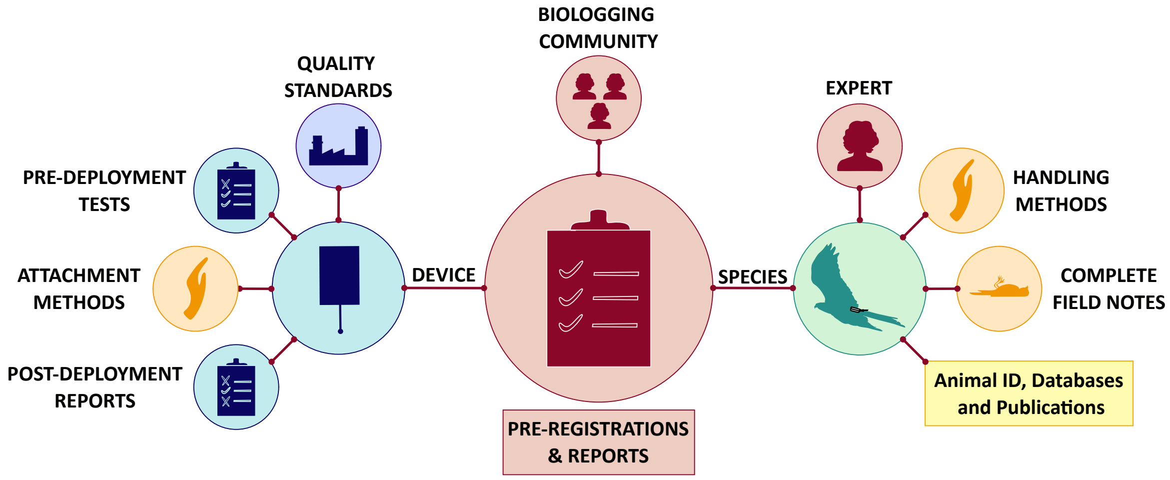

Figure 3: A pre-registration and post-reporting registry, both at the device and animal use level. Only devices meeting quality certification standards required by industry regulations are included. Each device is connected to documentation of pre-deployment tests, detailed attachment procedures and post-deployment 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 pre-registered 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.

data.

3. Demanding industry standards

As a community we should define what our acceptable ratio between the burden on animals and data obtained is and refrain from buying cheap and likely to fail technology. It is not acceptable (and in the European Union unlawful) to do a simple economic calculation weighing low unit price for accepting high failure rates; the wellbeing of the animals we handle is a currency that is too-often ignored. The biologging community should demand that industry define standards and impose external auditing and certification for devices brought to the market. In the wildlife tracking industry, establishing standards for device quality and performance, certified by impartial entities, could enhance accountability (Figure 4). 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 reduce the burden dramatically and have done so in remarkable ways (Bograd et al., 2010; Williams et al., 2020). The reduction in size, weight and increased reliability of devices are responsible for the surge in biologging research activity. By further improving device to animal mass ratios and by adjusting their shape and size, new devices have yielded new opportunities that were unimaginable a decade ago. Interestingly, the miniaturization of biologging devices has not resulted in a decreased device to body mass ratio borne by animals, a measure that usually and arbitrarily is set at a maximum of 5% (for terrestrial) or 3% (for birds) respectively representing the maximum device to animal mass ratio. Instead, the technological advances have been invested in equipping ever smaller species (Portugal and White, 2018) instead of lowering the burden. We could start by investing the advancements in miniaturisation and reduction of device weight into actually reducing the relative weight ratio of tag to animal mass instead of, and in addition to, continuing deploying biologging devices on ever smaller animals and/or longer data acquisition keeping religiously to the arbitrary 5% and 3% thresholds respectively (Meierhofer et al., 2024; R. P. Wilson, Rose, et al., 2021). Here we could certainly do better and rein in our greed for data and thus heavier devices. The relative weight ratio is not even considering the potential improvements that could be achieved by harnessing the effects of shape, form, placement and use of attachment method in interaction with the species' specific mode of movement and the media it moves through (Kay et al., 2019; Mizrahy-Rewald et al., 2023; Longarini et al., 2023).

However, as we will continue to rely on experimental technology to achieve groundbreaking research, even these devices should meet certain baseline published and agreed upon standards and procedures that they have to meet and go through before being considered fit for deploying on animals. Strictly speaking, testing devices on any animal has to be considered an animal experiment requiring the same level of ethical approval as biological research projects using animals require.

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 cases of failure or malfunction.

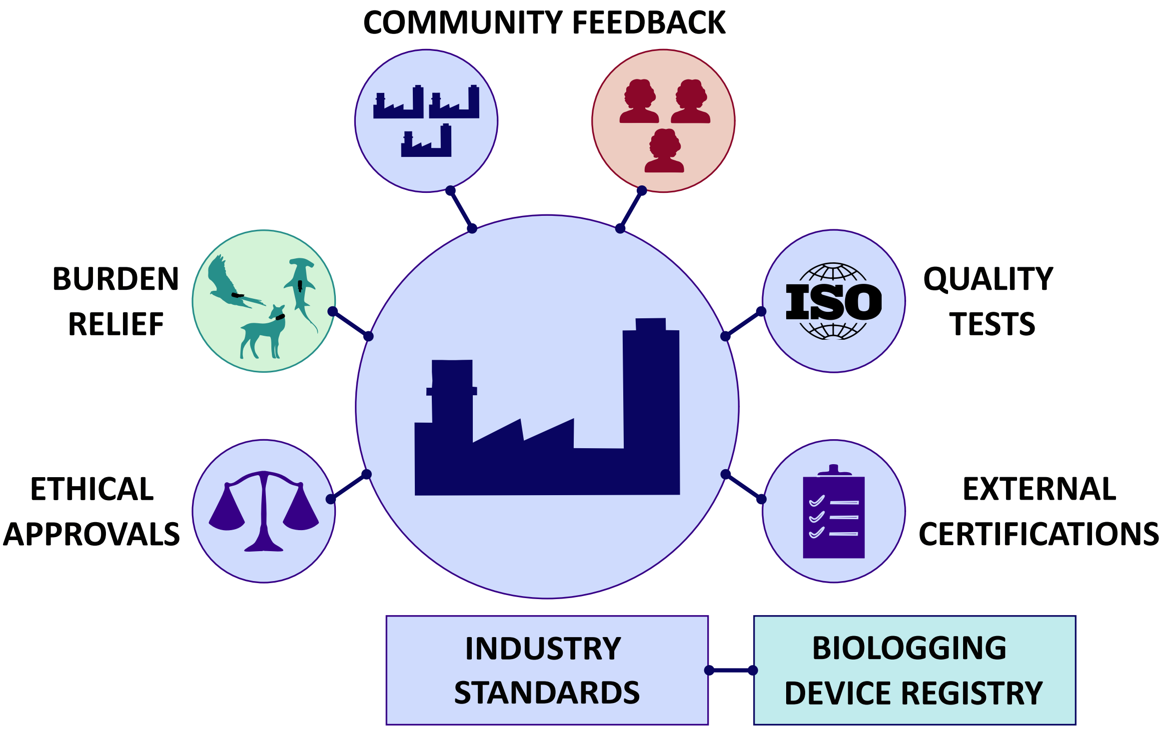

Figure 4: Suggested industry standards for biologging device production. To be included in the biologging device registry, tags must have certifications of standardized quality and testing, validated by external neutral companies, and ethical approvals for animal use. Manufacturers must collaborate with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

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 possibly even lead to lower the per datum expenses when the full-cost of the research life cycle is accounted for–both environmentally and economically. Standardization would also level the industry playing field by preventing price-based competition between the tech providers that compromises diligence in craftsmanship and testing at the cost of animal welfare and research quality. The biologging community should commit to demanding standards from the industry and additionally the permitting authorities and ethical commissions assessing the research proposals should enforce the use of certified devices only. A mandate to report and publish device performance, as part of the reporting on pre-registered tag and animal use procedure, would accelerate industry improvements.

4. Educational programmes and defining ethical standards for our field

As the field and subsequently the number of researchers deploying devices grows, we have to define and formalize the qualifications, training and skills required to be considered a biologging expert (Figure 5). To our knowledge, there is no curriculum or institutionally defined education programme that addresses the art of animal wearables and how best to deploy devices to animals and what the consequences of using alternative methods are. Just 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 (Forni, 2007; Erichsen and Hopla, 2021). Refinements in relation to deploying biologging devices on animals – more specifically the wildlife biologists' or veterinarians' experience and expertise and continued improvements in attaching devices to animals– are a crucial aspect that affect data quality and quantity in biologging studies. The educational programme would also establish pre-registration and post-reporting as an integral part of the responsibility that biologging experts have to provide the quantitative basis on which procedures can improve. Ultimately we should aim to challenge old habits and increase the pace of improvements in handling wild animals in the context of biologging studies. An aspect that could be much improved if it was evidence-based, academically organised, quantitatively assessed and formally developed. Some current legislation, and the way authorities interpret them, makes training scholars formally in handling and deploying biologging devices as part of ongoing research in the wild very difficult. But at the same time, courses aimed at acquiring skills and knowledge on laboratory animals (mice and rats) or other taxa that have little relevance for a specific research project are accepted qualifications for being permitted of catching, handling and deploying devices on wild animals.

Regulatory suggestions

With the growth of the field, the existing reporting procedures and trainings mainly geared towards working with laboratory animals as well as the mandated qualifications that allow researchers to conduct animal experiments in laboratories and animal housing facilities, are creating an increasing

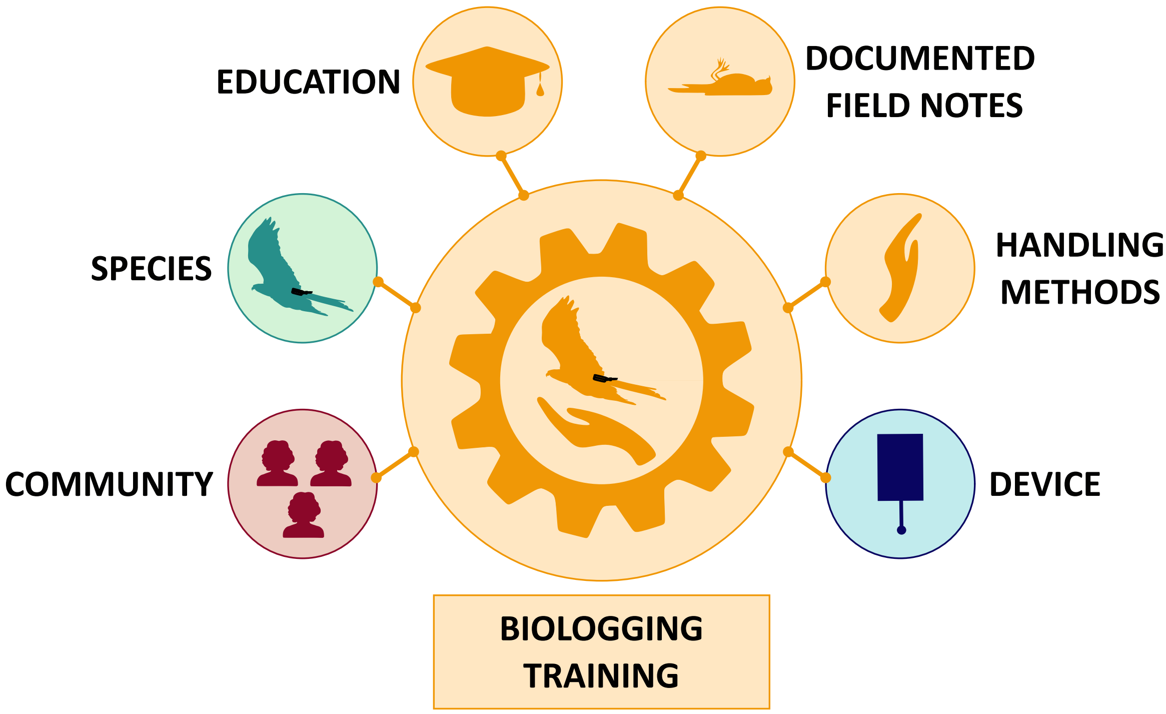

Figure 5: Our suggested educational programme for biologging experts. Comprehensive training integrates technological expertise with hands-on experience, it is therefore closely linked to both the biologging expert and device registries. The programme includes collaborative lessons and workshops among 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.

mismatch between the true requirements of the biologging field and the reported metrics and legal forms based on completely different presumptions. They are becoming an obstacle that needs to be addressed. The ethical applications, the pre-registration, and post-reporting procedures, and administrative forms and legal documents should be bespoke to the requirements of this meanwhile matured field to serve the purpose of improving the welfare and quality of research specifically for the tech-driven study of wild animals. Defining these procedures will also prevent competition nurtured by different levels of national requirements that may incentivise 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. In laboratory animal welfare, the same considerations have given rise to elevating 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) (see also Box 1).

That the Federation of European Laboratory Animal Science Associations (FELASA) explicitly considers sample sizes an important aspect of animal experiments should require, in some way, quantification on the ratio between animals burdened and realistic estimations of data obtained. There should not only be a mandate for obtaining an ethical approval prior to deploying biologging devices on animals, e.g. as part of a pre-registration mandate, but importantly a request for post-reporting after completion of the experiments/deployments and made available. Besides reporting successes and failures, the attachment method and procedure, materials used, and the duration of handling should be catalogued and reported as part of the crucial metadata. This should be part of a reproducible science approach, as it fundamentally affects the quality and volume of the data and has implications on cross-comparability of study results.

Ultimately, the proposed four action items should be embedded in the existing landscape of data bases, where data, people, devices, and industry can be better connected. Eventually, data collected on individual animals could be linked to their histories based on their unique animal ID (Wikelski, Quetting, et al., 2024) and linked to researchers, studies, and devices (Rutz, 2022) all of which have associated meta information.

Conclusions

As the field of animal bio-telemetry continues to grow and evolve, it is crucial that we establish a robust error culture; one which fosters open communication about failures, and prioritizes animal welfare. Thus, we can ensure that our technological advancements translate into ethical and effective scientific progress. The proposed initiatives, including the biologging expert registry, standardization efforts, and adoption of the bespoke 5R principle, represent crucial steps towards a more responsible, inclusive, and transparent research community. The aim of burdening animals with biologging devices should be to deliver information 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. Due to the logistical challenges and costs associated with tagging and tracking animals, we often face challenges with statistical power and/or robust experimental design (Yang et al., 2024); challenges that are shared among the field of ecology and evolution (Kelly, 2019; Yang et al., 2024). But, as outlined in Yang et al., 2024; Nakagawa et al., 2024 small studies can still be valuable if we prioritize transparent reporting of all results, including effect sizes and confidence intervals, regardless of whether they are positive or negative. Actions that would counter-argue the trivialisation accusation (Arrondo and Pérez-García, 2025). We need to emphasize theoretically informed, well-designed studies over mere statistical significance and encourage the publication of all findings to combat the file-drawer effect (Smaldino and McElreath, 2016; Smaldino, Turner, and Contreras Kallens, 2019; Stewart and 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 by increasing its credibility. Transparent reporting protocols, pre-registering studies, utilizing registered reports, archiving data and code, and importantly establishing a solid educational, ethical research based foundation for the use of animals in our field are steps we consider important. These practices can help to reduce questionable research practices, detrimental competition and misguided incentives. Naturally, achieving these goals comes with allocating worthwhile resources, mainly time, into activities yielding long term benefits to the field elevating quality over quantity at the cost of not being able to publish as many papers in as little time as possible.

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