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VIEWPOINT

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The case for open research in entomology: Reducing harm, refining reproducibility and advancing insect science

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Abstract

1. Open research is an increasingly developed and crucial framework for the advancement of science and has seen successful adoption across a broad range of disciplines. Entomology has, however, been slow to adopt these practices compared to many adjacent fields despite ethical and practical imperatives to do so.
2. The grand challenges facing entomology in the 21st century require the synthesis of evidence at global scales, necessitating open sharing of data and research at a pace and scale incompatible with the slow adoption of open research practices. Open science also plays a vital role in fostering trust in research and maximizing use of research outputs, which is ethically crucial for reducing harms to insects.
3. We outline these imperatives and how open research practices can enhance entomological research across a range of contexts. We also highlight the holistic nature of open science across the full research lifecycle through several specific examples of open research practices, which can be adopted easily by individual entomologists.
4. We do, however, argue that the responsibility of promoting, integrating and encouraging open research is most crucially held by publishers, including scholarly societies, which have leveraged widespread adoption in adjacent fields. Entomology must advance quickly to become a leading discipline in the open research transition.

KEYWORDS
open access, open data, open science, preprinting, preregistration, reproducibility

INTRODUCTION

Open science is defined as ‘transparent and accessible knowledge that is shared and developed through collaborative networks’ (Vicente-Saez & Martinez-Fuentes, 2018). This means that research is openly available, the process of its generation is publicly visible, it is developed in open collaboration with the wider community and/or it is available for downstream use by the wider community. This can involve one or many individual practices.

Open research practices can occur at every step of the research lifecycle, from inception of ideas through to their publication, and beyond, carried out as individual practices or in combination across stages of the research lifecycle (Figure 1). Open research strives to increase research access, reproducibility and scrutiny. There are a diversity of drivers underpinning the adoption of open research

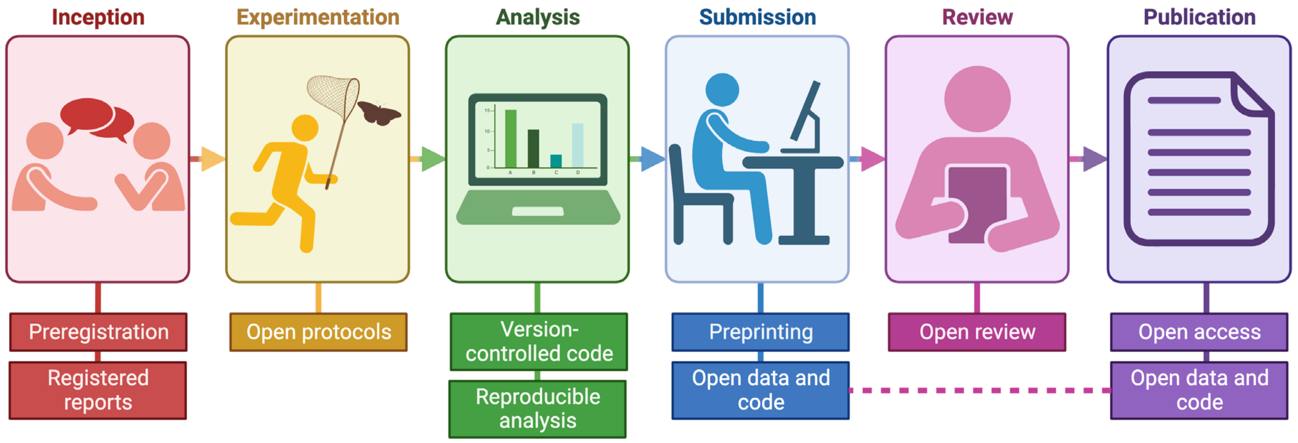

FIGURE 1 The research lifecycle from inception to publication with examples of open research practices given at each stage. Figure created with Biorender.

practices, from democratizing science and encouraging reflection throughout the research lifecycle, to facilitating collaboration and generating real-world impacts (Friesike et al., 2015). Although they are not without their challenges, a growing body of evidence demonstrates the success of practices like open access publication, preprinting and open data sharing in facilitating access to research, thus encouraging the adoption of open research practices across some disciplines and communities (Culina, Baglioni, et al., 2018; Munafò et al., 2017). Uptake has nevertheless been slow or poorly executed across some subfields of biological sciences (Roche et al., 2015), and some open research practices (e.g., open review, preregistration) remain generally poorly represented. Inadequate (or at least poorly communicated) incentives are thought to be partly responsible for this (Nosek et al., 2012; Reichman et al., 2011; Roche et al., 2015), but insufficient guidance and practical support are also a key barrier. Many researchers agree with the principles of open research but perceive them as too time consuming or challenging to adopt.

As academic journals adopt guidance or mandate open data and wider open research practices (Jenkins et al., 2023; Nosek et al., 2015), familiarity and alignment with the principles of open research become paramount for academic career progression and dissemination of research. Publishers too must understand developments in open research, not only to keep pace with industry standards but also to ensure that these practices do not introduce or exacerbate inequities (e.g., by introducing article processing charges that prohibit publication by researchers from many countries). Engagement with open research by both academics and publishers will also enhance the reach and impact of entomological research by making all facets of research accessible to non-academic audiences including the public, policymakers and practitioners (i.e., farmers, foresters, horticulturalists), enhancing the societal value of that research. Important progress is underway in fields adjacent to entomology, such as ecology, where publishing data and often underlying code have become required by most journals (Culina, Baglioni, et al., 2018; Jenkins et al., 2023). Entomology itself has, however, seen little concentrated effort despite the prevalence of several unique and crucial reasons for adopting these practices. We outline the practical and ethical imperatives for open research within entomology, from the need to synthesize data across studies to address global challenges, through the requirement for transparency to maintain trust and best practice, to reducing the harms incurred by killing or disturbing invertebrates. We also highlight what open research entails and how it can be encouraged, adopted and sustained within entomology.

TACKLING GLOBAL CHALLENGES

Greater accessibility and availability of research and data can help to address the grand challenges of our time (Luke et al., 2023), particularly through large-scale syntheses and meta-analyses (Culina, Crowther, et al., 2018). With global insect declines set against the dual threats of land-use intensification and climate change, entomology has many grand challenges to meet in the 21st century (Luke et al., 2023). Identifying the trends underpinning some of the most urgent global challenges in entomology, including climate change (Kaczmarek et al., 2021), land-use change (Méndez-Rojas et al., 2021), species invasions (Tercel et al., 2023) and biodiversity loss (Van Klink et al., 2020), requires rigorous research and data across a broad range of studies and contexts. Access to research, particularly early in the research lifecycle (e.g., via preprints or preregistrations), is paramount to avoid duplicated efforts and expedite the advancement of collective knowledge and progress towards addressing these grand challenges. By sharing research outcomes openly and as early as possible, hypotheses and mitigation strategies can be developed and refined without the latency traditionally introduced by peer review. Perhaps more profoundly, however, open research can facilitate the synthesis of large volumes of data across disparate contexts through open sharing of data in line with the FAIR principles (findable, accessible, interoperable and reusable; Hampton et al., 2013; Mouquet et al., 2015; Wilkinson et al., 2016).

Increasing data access was among the 61 priority grand challenges identified recently by Royal Entomological Society members, specifically to 'increase the accessibility of existing entomological data, including published and unpublished work, and raw data' (Luke et al., 2023). Meta-analysis has the potential to synthesize evidence based on multiple sometimes contradictory sources (Gurevitch et al., 2018), which is particularly powerful in resolving global patterns. It is possible to extract data from figures using open-source software even when raw data are not readily available, but this relies on clear presentation of data in specific types of figures (Lajeunesse, 2016). Availability of interpretable and formatted data is optimal though, given that the coarse data extracted otherwise can neglect properties such as variance, normality and heteroscedasticity, which many analyses require to fit pre-defined assumptions. Increasingly common requirements by journals for data availability statements and open data publication (Jenkins et al., 2023) may facilitate a massive increase in data archiving, alongside a growing range of accessible data repositories (Whitlock, 2011). Data availability statements and even open data mandates are not, however, always effective (Federer et al., 2018; Tedersoo et al., 2021) and publishers must proactively monitor and enforce the open sharing of data, such as by mandating data publication as a condition of publication. As well, research and data being accessible is only useful if that research is rigorous and robust, demanding trust and best practice among researchers.

FOSTERING TRUST AND BEST PRACTICE

The veracity of study outcomes and datasets can be compromised by both honest mistakes and malpractice, the identification and correction of which can be facilitated by open sharing of experimental intentions, protocols, data and code. Open research practices, such as preregistration, open protocols and preprinting, can aid in the identification of such instances before articles are accepted into the peer-reviewed literature, reducing potential impacts. Safeguarding reproducibility by reducing questionable research practices (such as 'p-hacking'; Fraser et al., 2018) is arguably the most widely known imperative for open research, especially in the wake of high-profile data fabrications that have shaken confidence in the integrity of invertebrate research (López Lloreda, 2023). Such cases of discovered malpractice tend to be unveiled by inspection of open data (Viglione, 2020), highlighting the power of open research in facilitating thorough auditing of datasets. Researchers evaluating the same dataset may also use different workflows or make different decisions during data analysis that lead to disparate results and conclusions (Gould et al., 2023); making data available as a part of manuscript publication facilitates re-analysis and evaluation of how alternative analysis methodologies affect conclusions.

For these benefits to be realized, openly shared research must be interpretable, accessible and complete. This need transcends open data, ideally involving sharing of hypotheses, methods and publications for scrutiny across the research lifecycle. Uptake of open research practices is hindered by various barriers, however, including the fear of ideas being 'scooped' (Penfold & Polka, 2020). This distrust manifests in zero-sum game theory in which researchers are less inclined to participate in open research when their colleagues do not. The goal of fostering trust and best practice therefore extends beyond simply establishing trust in published research to fostering trust between researchers by making open research practices more commonplace.

REDUCING HARM

Through its concern for morphologically and ecologically cryptic taxa and the need to survey highly diverse and abundant communities, entomology can necessitate the killing of many organisms, often rationalized by the need to protect, advocate for and benefit from the sacrificed insects. However, common collection methods (such as malaise traps) incur extraordinary bycatch rates for the targeted collection of specific taxa (Gonzalez et al., 2020), and pest control methodologies often have substantial non-target effects. Ultimately, both these and even targeted methods may cause harm to populations and/or individuals beyond those targeted for pest suppression. Harm to populations can occur whenever insects are lethally sampled (Gibbs et al., 2017) and is exacerbated by overzealous collection of target (Tepedino & Portman, 2021) and bycatch taxa, sometimes including species of conservation concern (Freelance, 2019). Although these harms are often likely to be negligible globally, they can nevertheless impact populations locally and oppose conservation efforts. There is an ethical imperative to reduce such harm and promote environmental stewardship across entomology (Costello et al., 2016; Fischer & Larson, 2019), in which open research can play an important role. Whilst new technologies and techniques are increasingly facilitating non-invasive insect research (Bjerge et al., 2023; Chua et al., 2023), the insect collection methods involved in most entomological research may also harm individual insects' welfare (Barrett et al., 2023; Fischer & Larson, 2019). Whilst there is currently no scientific consensus on whether insects feel pain, a recent review of neurobiological and behavioural evidence suggests that adults of multiple insect taxa meet many of the criteria in the Birch et al. (2021) framework for assessing animal sentience (Gibbons et al., 2022). If insects are sentient, then their welfare is morally important (Singer, 2002) and collection presents an obvious harm. As professional animal scientists responsible for the ethical use of our research subjects (Crump et al., 2023; Drinkwater et al., 2019; Sandall & Fischer, 2019), precautionary reasoning would suggest reducing harms to individual insects until more is known about their sentience.

In line with this reasoning and frameworks like the 'Three Rs' (replacement, reduction and refinement; Russell & Birch, 1959), entomologists should reduce harms to insects at both population and individual levels (Fischer & Larson, 2019; Montero-Castaño et al., 2022). Open research can help to rebalance the benefits of lethal entomological research against the ethical cost by facilitating wider use of the resultant data or specimens, and transparency to facilitate robust validation and scrutiny of results. The resultant wider availability and use of data is particularly important as it may reduce the need to re-collect similar data, preventing the death or disturbance of many more insects. Open research practices can facilitate the protection of insect welfare during experiments as well for the above reasons, but also by promoting the adoption of updated methods and the refutation of outdated practices, with the aim of enhancing welfare (Nawroth & Krause, 2022; and see Fischer et al., 2023). Increasing focus on the welfare of insects, concomitant with the mounting evidence for their sentience (Gibbons et al., 2022), can eventually be expected to introduce legislation that aims to protect their welfare (e.g., inclusion of decapods in the UK's Animal Welfare (Sentience) Act 2022; though see Freelance, 2019). Policies that promote insect welfare during collection, husbandry and experimentation will likely encourage, if not enforce, open research. For example, reporting on the ethical treatment of insects is now required by some scientific journals (e.g., *Animal Behaviour*). Alongside the ethical imperative of open research for animal welfare, considering animal welfare can also improve the validity and reproducibility of research (Cait et al., 2022; Loss et al., 2021; Soulsbury et al., 2020).

LANDMARKS IN THE EVOLVING OPEN RESEARCH LANDSCAPE

Whilst the benefits of open research are clear, some of the greatest obstacles to its adoption are a lack of comprehension of its constituent parts, inconsistent definitions of these concepts and lack of awareness of available guidance. Entomological publishers have begun to integrate, encourage and even enforce some of these practices, particularly open access, preprinting and open data, but there is still a great deal of progress to be made. Here, we outline and define several key open research practices spanning the research lifecycle (Figure 1) from inception of a research project through to dissemination of results to the community. We also discuss how individual entomologists, and the entomological community, can implement these practices to make entomological research more open.

Inception

Open research is ideally incorporated from the start of the research lifecycle, the inception of a research project. Given the opacity of the research process, it can succumb to undue flexibility, leading to changes in research methodologies, hypotheses and/or analyses (including practices like 'p-hacking') that are not transparent and compromise the integrity and objectivity of the research (Munafò et al., 2017). Declaring our hypotheses, methodologies and planned analyses at the start of a project through preregistration, the practice of publicly uploading experimental and analytical intentions ahead of initiating the research, can mitigate the problems of research flexibility. Preregistration does not prevent researchers from modifying their methodologies as necessary but ensures that they justify any deviation from a previously established plan, essentially distinguishing between prediction and postdiction (Nosek et al., 2018). Whilst preregistration is primarily purposed for empirical studies, it can also be applicable to secondary data analyses (Mertens & Krypotos, 2019; Van Den Akker et al., 2021). Some study types in other disciplines require preregistration, such as clinical trials, for which the stakes can be high for involved participants. Platforms like the Open Science Framework (https://osf.io/) facilitate dissemination of pre-registrations; discipline-specific platforms have also arisen.

Although preregistration adds to researcher workloads, the benefits (i.e., enhanced credibility, calibrated confidence in claims, reduced publication bias) arguably outweigh this cost (Nosek et al., 2019; Sarafoglou et al., 2022). It could, however, be argued that the cost is to individuals (i.e., time, reputation) and the benefit to the community (i.e., early access to ideas), thereby misaligning incentives. Individual benefits can drive voluntary behaviour, whereas community benefits that incur individual costs require community-driven changes (e.g., journal mandates). Importantly though, the benefits to individual researchers can be substantial; preregistrations are citable and trackable outputs that document the provenance of research ideas and methodologies. They also publicly demonstrate a commitment to integrity, sometimes flagged by publishers through preregistration 'badges' on final publications (Center for Open Science, 2023). Some argue that preregistration does not mechanistically address the challenges it is designed to since it can be exploited or used selectively, does not innately denote important or robust research, and may stifle explorative research (Pham & Oh, 2021). Preregistration does, however, increase transparency and shift the focus of research towards the assessment of theory and methods (i.e., the proposed research workflow) rather than the significance of results (i.e., the final outcomes; Van 'T Veer & Giner-Sorolla, 2016).

Journals can promote preregistration through publication of 'registered reports', which are effectively two-stage publications, comprising an initial peer-reviewed pre-registration from which the journal may agree to publish the final study so long as it adheres to usual standards and the agreed outline (Chambers, 2013; Gya et al., 2023; O'Dea et al., 2021). This shifts the evaluation of research to favour the significance of questions and hypotheses, and robust methodology, rather than favouring highly significant outcomes, somewhat mitigating selective publishing and publication biases. By essentially integrating preregistration into the publication process, registered reports further circumvent 'scooping' of research and the race to publish, helping scientists to prioritize robust science over rapid publication. Other benefits also apply to both preregistration and registered reports, including reduced duplication of effort, and making most effective use of research funding and time. Whilst preregistration provides researchers with a demonstrable output early in the research lifecycle (which is particularly valuable for early career researchers), the value of this is even greater for registered reports given their integration with the peer review process.

Experimentation

Of the different stages of research, experimentation is arguably often the most opaque and irreproducible, partly due to poor standardization of methodologies, user biases and differences in equipment or abiotic conditions. The need to concisely describe methods in publications has the potential to confound these issues; the accumulation of minute differences in approaches can contribute to disparate experimental outcomes. Publishing more comprehensive descriptions of methods in supplementary materials associated with papers offers one solution to this, but this is not always common practice and its publication is still subject to the same latency of peer review. Transparent publication of prescriptive protocols using platforms like Protocols.io can overcome these hurdles by presenting protocols as detailed step-by-step guides and facilitating community interaction. Publishing protocols ahead of manuscript submission offers similar benefits to preregistration (i.e., production of citable items, documenting provenance of ideas and signalling research integrity), provides an additional layer of scrutiny and, with validation of protocols by the wider community, increased confidence in their veracity. This is especially important for method development but can be equally valuable for alterations made to existing methods, their application to new contexts, or their compilation into complex workflows. Beyond validation and scrutiny, this also has the potential to facilitate the immediate uptake of new methods by the scientific community. Importantly, the success of open protocols is contingent on their accessibility, including their use of readily available equipment and open-source software (for which open data and code sharing are often paramount).

Analysis

Computational tools are central to life science research (Hannay et al., 2009), with entomologists increasingly dependent on data and code, which present new opportunities for open research. Open data (discussed in greater depth below) is not an isolated endpoint; there are many opportunities for open research during analysis (Lowndes et al., 2017). Coding-based data analysis and visualization (e.g., using R or Python) have facilitated highly standardized yet complex analyses (Ihaka & Gentleman, 1996). The rapid and widespread adoption of R-based data analysis in adjacent fields such as ecology is increasing the reproducibility of data analysis (Lai et al., 2019). Packages such as 'tidyverse' (Wickham et al., 2019) provide unified frameworks within which data can be imported, tidied, manipulated, visualized and programmed to address common challenges in data science. Whilst code can be shared in supplements alongside papers or on many open data repositories, integration with cloud-based platforms like GitHub facilitates curation of version-controlled code repositories to organize, track, share, discuss and collaborate on code-based analyses and other projects (Braga et al., 2023). Through the integration of all of the above, open, transparent and reproducible code-based research can truly be attained, ultimately culminating in streamlined open access publication of both code and data.

The constant development of novel analytical pipelines requires open sharing of code to make these advances accessible to the wider community, but open sharing of code is not solely restricted to novel methods. Given how critical analytical decisions can be for determining study outcomes and how many of these are deferred to coding-based analyses now, sharing these details can be crucial for transparency (Gould et al., 2023). Uploading open code is often thought to enhance scrutiny and robustness by allowing reviewers and readers to repeat analyses exactly as performed for the published research, but this conflates reproducibility (i.e., obtaining the same results using different experiments) with repeatability (i.e., the code can be re-run; Easterbrook, 2014). If code can be re-run and the same results are generated from the same data, this does not strictly indicate reproducibility, which would instead require independent analysis of the data. In this sense, open code is not a panacea for robust open research (Easterbrook, 2014) but at least clarifies the minutiae of the experimental steps taken to arrive at the results presented. Open code can help others conduct similar analyses in different contexts or contribute towards continuous stepwise development of analytical workflows, but it is most frequently shared by those with experience or training in coding (Strømme et al., 2022). Making sharing of code more comfortable for less computationally competent entomologists may require more prescriptive guidance and training opportunities across entomology.

Submission

Preprinting, the practice of sharing versions of manuscripts prior to peer review, has existed in mainstream research publishing for over three decades, during which time their annual frequency has increased over 63-fold (Xie et al., 2021). Evolving from an automated email server that distributed physics preprints, arXiv became the first preprint web service in 1991 (Xie et al., 2021), and the recent award of US $10 million from the US National Science Foundation and the Simons Foundation demonstrates its continued importance and community support (Boboris, 2023). Since arXiv's inception, similar servers, such as bioRxiv, have emerged to serve the life sciences, and platforms like Open Science Framework facilitate preprinting across a massive breadth of disciplines. Motivations to preprint vary, but the increased speed of dissemination of the research is a key factor, as is the establishment of precedence and improved accessibility of research for those without access to journal subscriptions. Hesitance towards preprinting tends to arise from fears of publishers penalizing preprinted work and a lack of familiarity (Fraser et al., 2022). Adoption of preprinting may also be hindered by the poor representation of preprints in promotion and hiring decisions, a lack of support from some funders and publishers, inconsistent functionality of preprint servers, peers not adopting the practice and the fear of 'scooping' of ideas (Penfold & Polka, 2020). These barriers are, however, likely to disappear as preprinting becomes more commonplace, now even integrated into some journal submission processes.

The benefits of preprinting for accelerating scientific progress, and for the career progression of individual researchers, are clear. Xie et al. (2021) found that preprints are available to read an average of 14 months earlier than their peer-reviewed counterparts, and preprinting is associated with five-fold more citations for the final peer-reviewed manuscripts, although these values may not account for biases in the papers submitted to preprint servers. Preprints are especially beneficial to early career researchers by immediately building their publication record regardless of the unpredictable latency of the peer review process (Ettinger et al., 2022; Sarabipour et al., 2019). This may explain the higher uptake of preprinting by these researchers (Wolf et al., 2021). Only around 4% of research articles are currently preprinted, however (Xie et al., 2021). Journals can encourage preprinting by integrating preprinting into the submission process, but also promoting preprints and openly inviting review of them from the scientific community, as described below (Ross-Hellauer, 2017). With a trend towards preprinting, researchers will likely consider whether publishers provide integrated preprinting when choosing a journal to submit to given that it streamlines their workload, incentivizing publishers to begin providing this service.

Review

Open review is an umbrella term for a range of peer review models, including disclosure of author and reviewer identities, publication of reviews following article publication and openly inviting wider participation in review (Ross-Hellauer, 2017; Schmidt et al., 2018). Open review aims to improve accountability, biases, inconsistencies, latency and incentives (Ross-Hellauer & Görögh, 2019) but, depending on the model used, some of these can be exacerbated. Open review can include any combination of signed, disclosed, editor-mediated (collaborative), transparent, crowd-sourced, pre-publication, synchronous and post-publication review (Ford, 2013), each of which presents significant benefits (Ross-Hellauer, 2017) but also requires the development of new infrastructure to support their adoption. Importantly, these practices do not need to be mutually exclusive. Open review also does not have to compromise anonymity of participants until the conclusion of the review process and is thus compatible with a double-blind approach (Fox, 2023). Of these, only open-identities review (identification of all participants in the review process) has potentially significant costs that make its adoption of uncertain benefit. Knowing the identity of authors can bias feedback given by reviewers (e.g., based on the identity, seniority or previous associations between the authors and reviewers; Bianchi & Squazzoni, 2022; Fox et al., 2023) and disclosing reviewer identities (e.g., signed reviews) will likely lead to many prospective reviewers disengaging from the review process (Didham et al., 2017; Rodríguez-Bravo et al., 2017; Van Rooyen et al., 1999) and reduce the degree to which reviewers will be critical in their assessments (Fox, 2021).

Some journals now publish reviewer reports, and often author responses, making peer review transparent and providing tangible evidence of review effort and rigour. Crowd-sourced review allows any community member to review research in a public process (Ford, 2013), overlapping somewhat with the transparent review, although identities are kept anonymous in many cases. New initiatives like 'Peer Community In' (PCI) essentially integrate preprinting with open pre-publication review for a collaborative evaluation of preprints (Zoccali & Mallamaci, 2023). This system has been successful enough that several journals now outsource peer review to PCI (O'Grady, 2021). As with any other peer review system though, the retention of a substantial pool of expert peer reviewers is a challenge for PCI, and the public nature of the review process may exacerbate inequities and restrict the reviewer pool to a narrow range of over-represented researchers.

Publication

Open publication of data and/or code is now commonplace and, in some cases, required prior to submission of manuscripts to facilitate appraisal of data and analysis during peer review (Jenkins et al., 2023). Data sharing can occur at various stages, the benefits conferred differing at each. If data are made openly available at the point of submission, reviewers can evaluate data and analyses alongside the manuscript, enhancing the rigour of peer review. A lot of open data are, however, shared after peer review once any revisions requested by reviewers are completed. Publication of data is particularly important if data are considered part of the associated research publication, rather than an addition to it, in which case the entomological community should treat sharing of raw data as an essential component of research publication. Publishing summaries of datasets in figures and tables is not an adequate substitute for raw data stored in an appropriate archive. Instead, the manuscript and dataset should ideally be published in parallel when possible, with journals requiring, and readers expecting, publication of the dataset in an appropriate repository as a condition of publishing the manuscript.

As discussed above, open data are also the necessary foundations of many meta-analyses, providing invaluable insights into grand, global challenges (Gurevitch et al., 2018). Given the increasing use of big data approaches in entomological contexts, addressing many questions in entomology, particularly those spanning broad spatial or temporal scales, requires open datasets spanning a wide range of data types. Data archiving is, however, less straightforward for long-term studies (Mills et al., 2015) or for studies concerning rare species (i.e., those of conservation concern; Lindenmayer & Scheele, 2017). Pragmatic exceptions in open data policies can mitigate potential adverse impacts of those policies whilst preserving the expectation that researchers include raw data as part of their research publications. Data publication has the potential to increase the return on investment in science vastly by facilitating wider use of research outputs (Piwowar et al., 2011), but the associated metadata must be complete, clear and easily interpretable (Whitlock, 2011). The benefits of data sharing, including re-use of data and acceleration of scientific discovery, must be made clear to researchers (which this article attempts to address in part). Further, appropriate guidance for data archiving best practice in entomology should be provided by scholarly societies and journals, particularly surrounding curation of easily accessible and interpretable descriptions of datasets (Roche et al., 2015). We also require a shift in academic culture to accept honest mistakes and human errors and to decrease the stigma around correcting or retracting papers where necessary.

Perhaps the most widely known example of open science is that of open access publication, with a significant increase in adoption of this practice by journals since its inception in 1993 (Laakso et al., 2011). Open access publication makes research freely available to researchers, policymakers and the public (Björk et al., 2010), irrespective of geography, socioeconomic factors or politics. Even two decades ago, authors were generally positive about open access based on the principle of free access to scientific literature, and cited unfamiliarity with participating journals as the most prominent barrier (Swan & Brown, 2004), although financial costs are now recognized as a greater barrier (Bahlai et al., 2019). Funder mandates for open access are increasing and often cite the laudable principle that the results of publicly funded research should be publicly available. Given the upfront costs of open access though, mandating it risks increasing inequity in the ability to publish given the unequal availability of funding globally and by career stage/position (Bahlai et al., 2019; Chilimo et al., 2017; Kwon, 2022). This may also leave authors susceptible to exploitation by predatory or unethical journals (Beall, 2012; McCann & Polacsek, 2018) and could, in turn, erode the quality of scientific literature as poorly vetted, erroneous and even fabricated research begins to survive decreasingly rigorous publication processes. Fee waivers for the 'article processing charges' associated with open access publishing are designed to address such inequities but are often insufficient in mitigating the problem (Kwon, 2022), meaning that further development is required to ensure that this component of open research achieves its goals.

CONCLUSION

Open research has never been more accessible nor more important. There are both practical and ethical imperatives for the adoption of these practices in entomology, specifically. Entomology is poised to address a plethora of grand challenges throughout the 21st century for which open access to research and datasets will be vital. Also, the scale at which invertebrate populations and individuals are killed, disturbed and/or used in entomological research creates an ethical need to make best use of the resultant data.

Though the benefits of open research are many, there remain hurdles to making entomology more open. In particular, there must be a cultural shift in which open research is both expected and supported by the entomological community. A cultural shift favouring open research may seem unlikely, given the deeply rooted traditions of independent research and journal publishing in the discipline, but such shifts can happen quickly; for example, whilst sharing of research data was once commonly limited to 'upon reasonable request', it is now the norm, and largely uncontroversial, for journals in ecology and evolution to require data sharing as a condition of publication (Culina, Baglioni, et al., 2018; Reichman et al., 2011; Roche et al., 2015). Such a cultural shift must be led by scholarly societies, publishers and funders through both mandates and incentives (e.g., badges, public recognition) and community education.

We must also ensure that the emphasis on making research open, accessible and societally relevant does not have unintended negative consequences, including the stifling of fundamental ('blue skies') research and the autonomous, pragmatic and curiosity-led nature of academic research (Düwell, 2019). We must also endeavour to distribute the costs of open research equitably, both in terms of financial barriers (e.g., open access article processing charges) and workload, the extent of which differ geographically and between career stages (Bahlai et al., 2019). To ensure equitability, participation in open research cannot be 'all-or-nothing'; variability in the ability of researchers to participate in the different aspects of open research is inevitable and must be accepted. Thus, whilst we have provided guidance for a holistic approach to open research, and we encourage researchers to participate in as many of the above open research practices as possible, we must also recognize the variable constraints on individual researchers.

The responsibility of ensuring equitable access to open research rests on scholarly societies (especially those that publish journals), publishers, funders and institutions. To advance adoption of open research, organizations can look at the range of open research practices detailed above and consider how they can integrate, support and encourage adoption of these practices across the research lifecycle. Publishers can integrate streamlined preprinting and data archiving into their submission processes to reduce workloads and provide funding to support data or article processing charges for authors unable to afford them. Until equitable access to open research is fully supported, the workload and challenges posed by engaging in open research must be recognized, particularly for early career researchers and those in global regions lacking funding (Bahlai et al., 2019).

Other resources offer comprehensive evaluations of the different practices encompassed by open research (UK Reproducibility Network et al., 2023), the full breadth of which should be explored and considered in the context of entomology. Acceptance of open research is increasing, with the potential to improve quality assurance, knowledge generation and interdisciplinarity substantially; this may fundamentally alter how we publish, read, interpret and advance research (Friesike et al., 2015). Whilst individual participation is crucial, the role of entomological publishers in promoting, integrating and mandating open research practices cannot be understated. They can take inspiration from a plethora of successful examples in adjacent fields, such as ecology (where data sharing is commonly mandated, registered reports are emerging and integration of open research practices into submission portals is increasing). Alongside integration of preprinting and data archiving into submission processes, open review and preregistration are paving the way towards fully open publishing. Entomological publishers and scholarly societies must be proactively involved in this inevitable transition and, ideally, become leading voices in the wider adoption of open research across biological sciences and beyond.

AUTHOR CONTRIBUTIONS

Jordan P. Cuff: Conceptualization; visualization; writing – original draft; writing – review and editing. **Meghan Barrett:** Writing – original draft; writing – review and editing. **Helen Gray:** Writing – review and editing. **Charles Fox:** Writing – review and editing. **Allan D. Watt:** Writing – review and editing. **Emilie Aimé:** Conceptualization; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

Emilie Aimé is employed by the Royal Entomological Society (RES) as Head of Publishing; Jordan Cuff, Meghan Barrett, Allan Watt and Emilie Aimé sit on the publications committee of the RES; Jordan Cuff and Allan Watt are Editors-in-Chief of the RES journal *Agricultural and Forest Entomology*; Charles Fox is Editor-in-Chief of the RES journal *Ecological Entomology*; most co-authors are members or fellows of the RES.

DATA AVAILABILITY STATEMENT

No data were used or generated for this manuscript.

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