



Conservation-led palaeolimnology: a review of applied palaeolimnology and lessons to improve accessibility and value to conservation practice

Ben Siggery¹ · Helen Bennion · Richard Murphy · Stephen Morse · Mike Waite

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Abstract The integration of palaeolimnology into conservation practice is crucial for effective ecosystem management and restoration. Palaeoecological data provide a unique long-term perspective on key ecological challenges and enable decision makers to better understand pre-disturbance conditions, natural system dynamism and responses to change. Despite this there exist well-recognised accessibility issues and a clear research-implementation gap, in particular, poor communication and lack of understanding of conservation practitioners' constraints. This study evaluates the accessibility and value of

palaeolimnological research to conservation practice by interrogating 60 key applied research papers identified via a rigorous pre-screening process to ensure relevance. The papers were assessed on the use of best practice accessibility criteria, from knowledge-exchange literature, and conservation-practitioner feedback was gathered on the value of conservation recommendations made within the papers. Despite widespread recognition of the importance of accessible research, our review reveals that essential accessibility criteria are inconsistently applied. Although there has been an increase in accessibility practices over time, co-production practices (including co-authorship, co-design of research, and linkage to relevant environmental legislation), showed no significant increase, despite being advocated for by the research community. Practitioner review highlighted the need for research to provide clear, actionable recommendations, and papers that detailed specific management or restoration guidance were particularly well-received, as were those that considered financial implications and summarised their findings more clearly. Equally, many papers were criticised for overly technical language and poor expression, generic suggestions, and a lack of practical consideration in their recommendations. The study highlights the importance of improving accessibility and co-production of knowledge to ensure that research outputs are accessible, relevant, and feasible to guide conservation efforts. To enhance the relevance and impact of applied palaeolimnology, we propose five

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B. Siggery (✉) · R. Murphy · S. Morse
Centre for Environment and Sustainability, University of Surrey, Guildford, UK
e-mail: Benjamin.siggery@surrey.ac.uk

R. Murphy
e-mail: rj.murphy@surrey.ac.uk

S. Morse
e-mail: mike.waite@surreywt.org.uk

B. Siggery · M. Waite
Surrey Wildlife Trust, School Lane, Woking, UK
e-mail: mike.waite@surreywt.org.uk

H. Bennion
Department of Geography, University College London, London, UK
e-mail: h.bennion@ucl.ac.uk

key recommendations: (1) situate recommendations within existing practice and knowledge; (2) consider the practicalities for practitioners, including material and socio-economic aspects; (3) use clear and simple language; (4) employ easy-to-interpret diagrams and bullet points for recommendations; and (5) improve accessibility of older work. These recommendations are key in helping palaeolimnology progress towards a ‘gold standard’ of applied research, where it can be employed to greater effect to support conservation practice.

Keywords Palaeoecology · Biodiversity · Applied science · Ecological Restoration · Knowledge co-production · Habitat management

Introduction

Freshwater ecosystems, despite occupying less than 1% of the planet’s surface, have been disproportionately impacted by human-induced environmental change and have experienced some of the highest biodiversity losses across all ecosystems (Ahmed et al. 2022). They are subject to multiple confounding anthropogenic pressures such as pollution, nutrient enrichment, land-use change and warming temperatures, worsened by their inherent vulnerability (Williams-Subiza and Epele 2021). Rapid action is needed to limit further damage as climate and population pressures continue to grow, and European freshwater biodiversity recovery has slowed to a halt (Haase et al. 2023). Palaeolimnology, focused on the reconstruction and interpretation of lake histories from their sediments, has been developing rapidly as a field of applied science with the potential to address some of these challenges and is considered one of the most applied of the palaeo-sub-disciplines (Smol 2008; Jeffers 2013). To date, it has played a key role in informing decision making for wetland conservation, including lake restoration (Short et al. 2022), pond management (Sayer et al. 2012) and species reintroductions (Bennion et al. 2024) to name but a few. In Europe, following the momentum gained by its use in setting reference conditions in the EU Water Framework Directive (WFD), palaeolimnology has been employed in many commissioned studies to assess habitat quality and to set recovery targets (Bennion et al. 2011). Similar accomplishments have been seen

in North America (Shaw Chraïbi et al. 2011), China (Lin et al. 2019), New Zealand (Short et al. 2022), and many other parts of the world where palaeolimnology has also been used to support lake conservation, management and restoration.

Despite the successes of palaeolimnology as an applied science, there is still a well-recognised ‘research-implementation’ gap. In this, the conservation-practitioner community remains, in general, disconnected from palaeolimnological research (Saulnier-Talbot 2015; Clarke and Lynch 2016). This disconnect is an issue throughout conservation science and is by no means exclusive to palaeolimnology (Sutherland et al. 2004). It results from a variety of factors, including misconceptions around the role and utility of palaeoecological research, as well as time constraints and financial barriers of practitioners (Saulnier-Talbot 2015; Goodenough and Webb 2022; Siggery et al. 2023). The disconnect is also exacerbated by the poor communication of research to practice and the limited accessibility of published work (Davies et al. 2014). In particular, conservation practitioners have highlighted their need for more and better access to applied case studies (Siggery et al. 2023). Whilst the existing body of palaeoecological literature does contain many applied studies, it appears that these may not be sufficiently accessible (both in terms of actual accessibility and in their presentation of information for conservation practitioners) or may not be presenting findings that are of explicit value to conservation practice.

Actual accessibility, e.g. via open access publication, is known to be a key limitation to the ability of conservationists to deliver evidence-based practice, not only for palaeolimnology but for conservation science more broadly (Sunderland et al. 2009). In a study of conservation professionals by Fabian et al. (2019), a lack of access was rated as the second highest reason that academic work was not consulted. Whilst this has undoubtedly improved in recent years as open access practices have expanded, there remain issues with accessibility of pay-to-read science for many conservation practitioners (Roche et al. 2022). For palaeolimnology, this is compounded by the fact that studies are often published in specialist palaeoecological journals, which would not commonly be browsed by conservation professionals and policy-makers, in comparison to a conservation or ecology-focused journal (Schafstall et al. 2024). In addition,

the way in which academic papers are written and presented can have a direct relation to the usability and interpretability of the findings for practitioners, where heavy use of academic jargon contributes to inaccessibility (Brunson and Baker 2016; Roche et al. 2022).

In a review of conservation-palaeobiology literature, Groff et al. (2023) found that 64% of studies made only cursory reference to conservation and how their findings may be utilised in practice. Brief comments in the concluding sections of academic papers, intended to support conservation work are disappointingly common (Ehrenfeld 2000). This coincides with increasing pressure for researchers to evidence the academic value of their work, which often stands at odds with the potential impact for conservation practice (Gibbons et al. 2011). The drive towards publication in a higher ‘impact factor’ journal as an important consideration for assessing the contributions of individual researchers, and indeed university departments, may have led to a rise in publications that are applied in name only or are lacking in utility for practitioners (Dietl et al. 2023). Many institutional structures still incentivise rapid production of peer-reviewed articles over applied, engaged science and outputs (Norström et al. 2020). So, whilst applied research is not a rarity, there is a spectrum along which it sits, ranging from brief statements of potential applicability to fully integrated, co-produced research with practitioners that result in clear recommendations for application in conservation practice.

There is recognition of the above problems by the academic community and many authors have written about solutions to short-comings in communication, and how to design, conduct and disseminate better applied palaeoecological research, drawing on wisdom from other forms of translational research, such as translational ecology (Clarke and Lynch 2016; Flessa 2017). One of the key approaches promoted is the co-design and co-production of research (Gillson et al. 2021). For research outcomes to be useful and applicable, projects benefit from being designed from the bottom-up rather than top-down, being led by those they are designed to empower rather than the focus being decided solely by the academic researcher (Enquist et al. 2017). Additionally, linking the findings back to relatable outputs is advocated, for example, including reference to environmental policy and law, which naturally facilitates relevance to decision

makers and practitioners (Flessa 2017). In a European context, this was achieved with regard to implementation of the EU Water Framework Directive (Bennion et al. 2011), and there are clearly open opportunities to do so within the post-Brexit evolution of the UK environmental policy landscape. However, despite such progress towards improved applied palaeolimnology, communication remains an issue between researchers and conservation practitioners (Goodenough and Webb 2022; Groff et al. 2023).

This study examines the existing body of applied palaeolimnological work to (1) investigate the development of applied work over time; (2) ascertain whether the palaeolimnology research community is ‘*practicing what we preach*’ in terms of conservation practice; and (3) identify which areas, at the interface between research and practice, might benefit most from enhancement. The research specifically identifies applied academic works that make conservation-management recommendations as a result of palaeolimnological analysis and examines the characteristics of these against recommended accessibility practices. The research included consultation with conservation practitioners on the value and interpretability of each study. This was used to elucidate ways to optimise communication of palaeolimnological studies and identify from relevant papers, the ‘gold standard’ features of accessible and relevant applied research for conservation practice that could usefully inform future outputs.

Materials and methods

Literature search and screening

In order to investigate the published body of applied palaeolimnological work, the research employed a review-style approach, examining the trends of applied literature published in academic journals. Grey literature was excluded as the aim of the research was to explore challenges around specifically academic publication of palaeolimnology. Data were gathered initially using Boolean logic searches of three online databases; Web of Science, PubMed and Scopus to improve the comprehensiveness of the search (Watson and Medeiros 2021). Relevant literature was located through the keywords “paleo/palaeolimnology” and “conservation”, using operators in

the search to allow for variations in spelling and use of root words. There were no temporal, linguistic or geographic restrictions placed on the literature search. Taking this approach, searches were conducted in February 2024. An additional search was used to supplement the gathered literature, as it became apparent that some highly relevant studies in the *Journal of Paleolimnology* were not detected by using “paleo/palaeolimnology” as a search term for abstract, title and keyword queries due to it being superfluous in the context of the journal. Additionally, some relevant studies use the more general term “paleo/palaeoecology” instead, perhaps due to search-engine optimisation or fitting the article to the chosen journal. In order to capture these additional articles, a further query was conducted on each database using “paleo/palaeoecology”, “conservation” and “ponds” or “lakes”. This was carried out as above, using operators to account for variation and searching only in title, abstract and keywords where possible. Additional details on search terms used can be found in Supplementary Material 1.

A PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) Framework was developed to structure the literature review, and ensure transparency in the criteria chosen to narrow the search to the most eligible articles for the research (Page et al. 2021). The screening process for literature is shown in Fig. 1. This was employed to review the articles and confirm their content met the study-inclusion criteria. To be eligible, the study must i) use palaeolimnological methods to collect primary data, or use secondary data originally captured via palaeolimnological methods; ii) use the results of the study to make explicit recommendations for conservation; and iii) be an original research piece; not a review, modelling/methods or perspective piece. The intention was to remove pure research, theoretical and conceptual articles, to retain those which were explicitly applied studies. A total of 179 unique articles were screened against these criteria. For the final step of article screening, studies were read in full and judged against the protocol used by Conservation Evidence, an initiative which summarises and synthesises academic literature for conservation practitioners, as a basis for inclusion in their database of conservation actions (Bladon and Smith 2019). Specifically, articles were included/excluded when judged against their inclusion statement “*Could the action be put in place by*

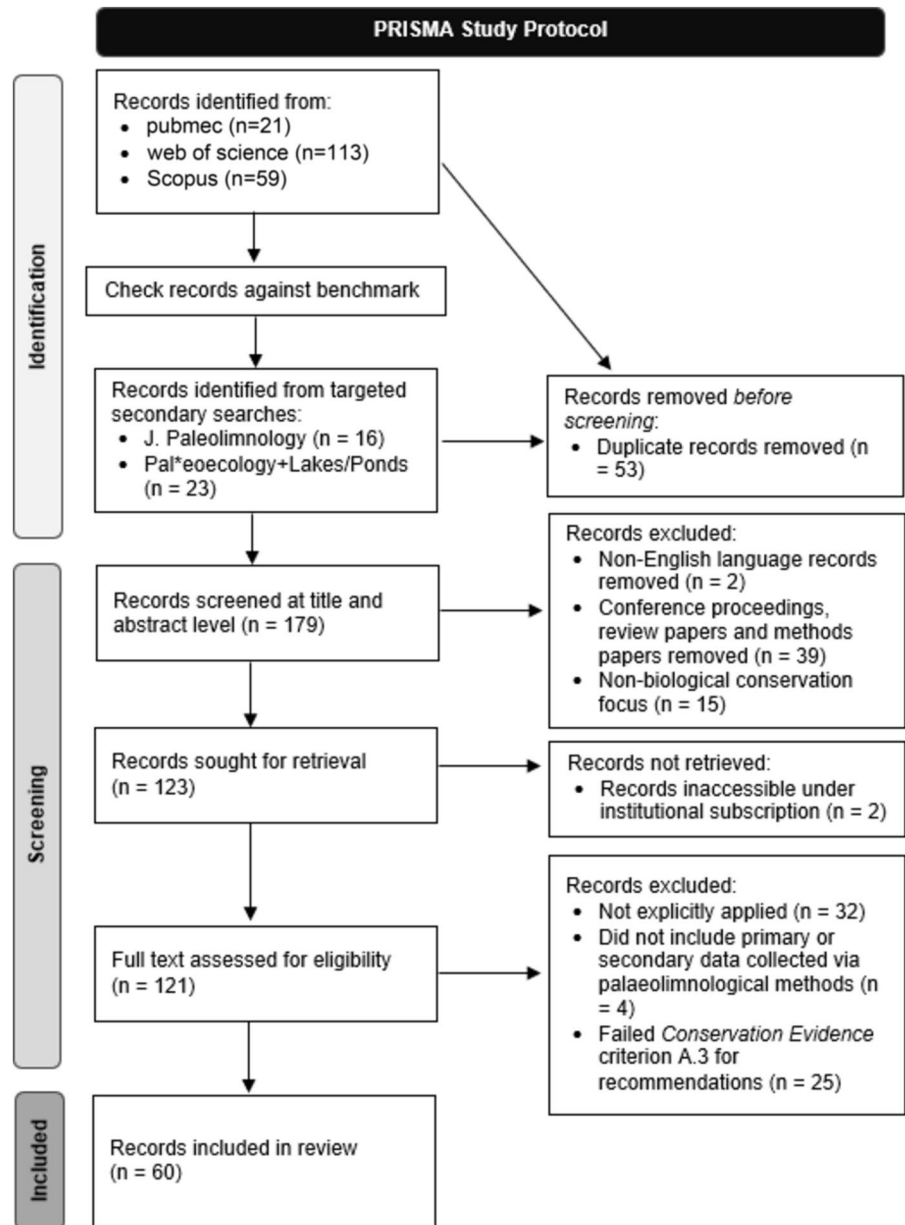
a conservationist/decision maker to protect, manage, restore or reduce impacts of threats to wild taxa or habitats, or control or mitigate the impact of the invasive/problem taxon on wild taxa or habitats?”. In this way, articles with no discernible action for practitioners were removed. Many articles had multiple recommendations but were considered as one article i.e. only one recommendation was needed to meet the above criteria for the article to be included. A total of 60 articles met the above criteria and were subsequently further examined (Supplementary Material 2).

Post-screening analysis

The selected articles were assessed against a set of seven ‘accessibility criteria’ (in-article signposting; accessible summaries; freely accessible article and data; study co-authorship and co-design; relevant legislative tie-ins), each of which is a recommendation for good practice that has been suggested by those engaged in this field as beneficial in overcoming evidence-practice gaps (Birks 2012; Saulnier-Talbot 2015). The criteria selected, an explanation of how they have been interpreted here and some key references to support each criterion are listed in Supplementary Material 3. Data were also collected about the nature of each article, including proxies utilised, location and geographic scale, study resolution, dating methods and if it was a single or multiple site study. Additionally, relevant metadata were collected for the characteristics of each article, including journal of publication, journal type (management focused, general ecology or palaeo-focused). All required data and metadata were available for all 60 articles.

The ‘conservation value’ of each article was also assessed, and a score allocated. This was a qualitative process whereby recommendations from each article were extracted and circulated to a group of 30 conservation practitioners for a single round of reviews. The practitioners came from a variety of organisations involved in wetland management, representing a variety of career stages at non-governmental organisations (NGOs), statutory environmental bodies, local conservation organisations and private consultancies. The majority of practitioners were based in south-east England and worked for NGOs (Supplementary Material 5). Each practitioner who responded was provided with a randomised sample of 10 of the 60

Fig. 1 PRISMA structure for literature screening, based on guidance in Page et al. (2021). See Supplementary Material 1 for further details



extracts for review and instructions on how to assess them (Supplementary Material 4). Each extract was rated with a single score on a scale of 1–5, with 1 being of minimal value and 5 being extremely valuable ('value' being referred to as 'useful' in Supplementary Material 4), as an indication of relevance to conservation practice. Practitioners were asked to equally consider the practicality, clarity, and usefulness of the extract in their deciding of the single given score and to provide a brief written justification for

the score. They were provided with a worked example, which was rated by the lead author and reflected on all three elements (practicality, clarity and usefulness) in the written justification. A minimum of three separate practitioner reviews were collected for each extract, as some practitioners did not review all 10 of the provided extracts; 4 reviews was the maximum received by any extract. Practitioners were not provided with the full article unless requested.

Simple descriptive statistics, such as percentage of total articles, were generated for the characteristics investigated. This was calculated for study location (% per country), journal type (% per journal type), dating *n* approach (% per dating method), and biological proxies utilised (% using each proxy) across all articles ($n=60$). This also included for each of the accessibility criteria listed above, again across all articles ($n=60$).

Additionally, a mean and median of conservation-value scores were calculated for each extract. Median scores were assessed as these provide better representation of skewed data with outliers than mean scores. Correlation coefficients between conservation-value scores and year of publication were also calculated. Bar charts were generated using Microsoft Excel. NVivo version 1.7.1 (Lumivero 2022) was used to thematically code practitioner responses and identify common patterns in comments on each extract's usefulness, clarity of expression and practical considerations. The coding was inductive and iterative using pre-defined code categories (explained in depth in Supplementary Material 6). Contingency tables (Chi-square test) were used to look for associations between frequency of codes and median conservation-value scores.

Study limitations

Despite careful research design, it is inevitable that the search terms employed in this study will not have captured every paper with useful conservation recommendations made from palaeolimnological research. Firstly, there were limitations placed on inclusion criteria, such as excluding non-English language articles which therefore limits the study to only a subset of the global literature. The possibility of missing relevant articles raises an interesting issue concerning careful choice of keywords and well-written titles and abstracts, as discussed by Bjune et al. (2015). There are notable pieces of work such as Madgwick et al. (2011), referred to as a 'bright spot' of conservation-palaeo interactions by Groff et al. (2023), that were missed by the search terms used in this study. Upon examination of that case, this was due to the absence of the term "conservation" within the abstract, title or keywords of the paper, despite reporting very clear recommendations for habitat restoration at Barton Broad (the case study site).

Another consideration is that prevalence of accessibility criteria could be influenced in some cases by journal-submission requirements and/or author guidelines as well as changing standards in scientific publication, both of which must be considered when reviewing these results. In addition, the use of groups of three or four different practitioners for reviewing each set of article extracts meant that there was inevitably some degree of inconsistency between reviews, and thus it was difficult to examine results empirically for trends or indeed to calculate between-rater reliability. It was not, however, realistic for each respondent to review all 60 extracts, given that participation was voluntary and no compensation was provided. Despite this, there is arguably a benefit to taking a breadth-rather-than-depth approach, as it meant that a wide range of views from individuals across different subsectors of conservation were represented.

This review is not intended to be a definitive assessment of all palaeolimnological research applied to conservation but rather a small sample to provide a general picture of how studies within this field are considered by practitioners. It is important to reiterate that the aim was not to judge the value of the research, but to attempt to measure of how the current literature is perceived by practitioners and the components of this perceived value.

Results

Study characteristics

The body of work was varied in methods employed and geographical location, as well as the journal of publication. A total of 50 of the 60 articles reviewed utilised radiometric dating approaches. Other approaches included use of secondary data, museum specimens and historic maps. With regards to biological proxies, the most frequently utilised were diatoms (55%), macrofossils (42%) and pollen (18%). There were slightly more studies that utilised only single proxies (57%) in comparison to a multiproxy approach (43%). Three studies also combined contemporary data with the palaeoenvironmental data. A total of 53.3% of articles were published in generalist environmental and ecological research journals, whilst only 28.3% were published in journals focused on conservation applications. The remaining 18.3%

were published in specialist palaeoenvironmental publications. The most common journal was the *Journal of Paleolimnology* (15%), followed by *Aquatic Conservation: Marine and Freshwater Ecosystems* (13%). Geographically, the majority of studies were from the United Kingdom (27%), the United States (14%) and Canada (12%). Studies were relatively scarce in South America, Africa and Asia, although China (7%) and the African Great Lakes (7%) were particular hot spots.

When assessed against the accessibility criteria, there was variation as to which criteria were fulfilled across the selected articles (Fig. 2). Accessible summaries were the least common feature present, with only 6.5% of studies using either a graphical abstract or an “implications for practice” section, and no studies using a plain language summary. Similarly, accessible data sources were not available for 68.3% of studies, though four offered to provide data on request. 11.6% of those which did provide data in their supplementary materials did not do so in an easily editable format (as per Open Data guidance), for example in image-based PDFs, or already formatted in stratigraphic plots. Additionally, co-authorship and co-design inputs from conservation practitioners were not common practice, with only 31.6% and 35% respectively of papers having these characteristics. Most non-university authors and contributors

were from other research bodies (e.g. Natural History Museum, United States Geological Survey), which were not considered as practitioners that would be using the papers to inform management decisions. Relatively few co-authors were from “on the ground” conservation bodies (e.g. NGOs such as *The Nature Conservancy* or public bodies such as *Environment and Climate Change Canada* formerly *Environment Canada*). An equally uncommon feature was a linkage to relevant conservation policy and legislation, with only 36.7% of articles mentioning associated site designations, protected areas or environmental legislation. The most commonly cited legislative links were the EU Water Framework Directive (10%) and the UK system of protected Sites of Special Scientific Interest (8.3%). In addition, a large proportion of the work was not freely accessible online. Only 38.3% of papers were officially open access, though an additional 25% were hosted via third party websites such as ResearchGate or other institutional research repositories (e.g. *UCL Discovery*). The most common accessibility feature was the use of clear signposting of readers to the conservation recommendations, via use of section headings or subheadings (e.g. an “*Implications for Conservation*” section or similar) which 63.3% of articles utilised.

The number of applied papers generally increased over time, with some bumper years with

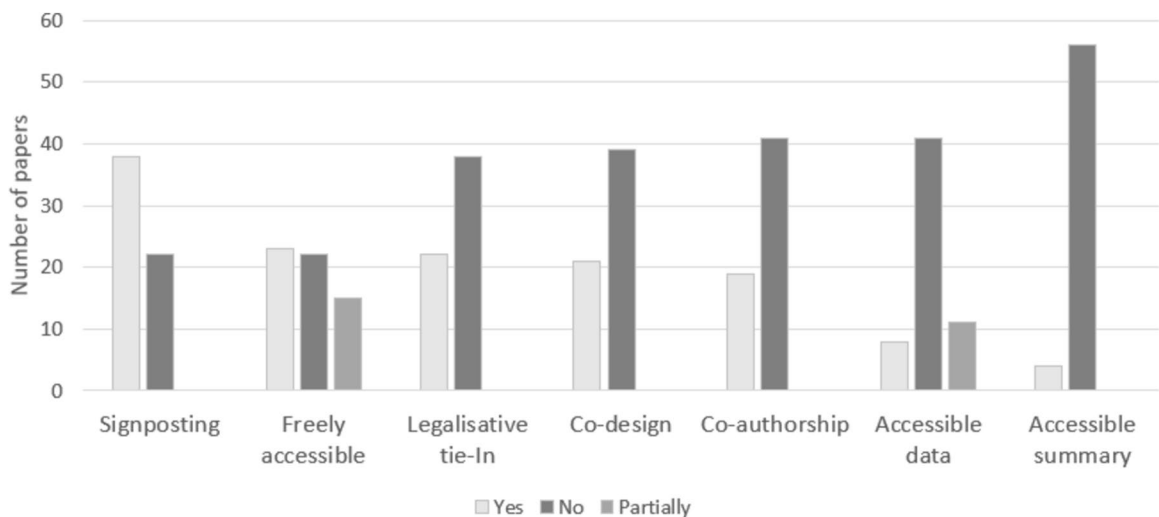


Fig. 2 Number of papers which use and do not use each of the accessibility criteria. ‘Partially’ is used to represent papers that were only accessible via third party repositories, and that only

provided data on request or in a format which did not conform to Open Data guidance

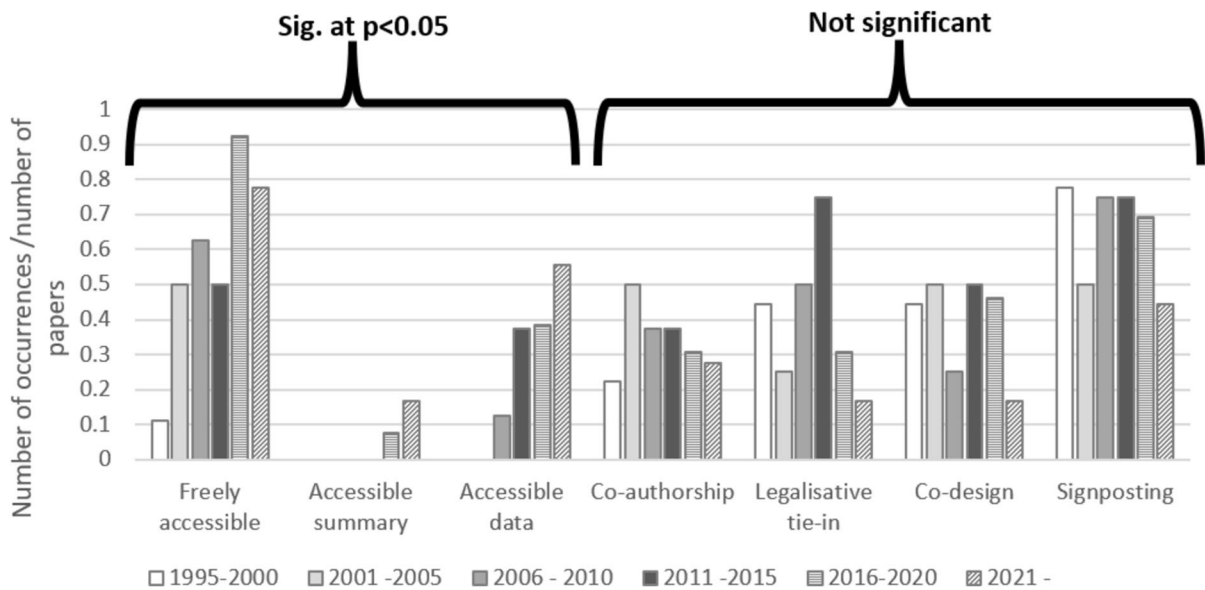


Fig. 3 Frequency of use of accessibility criteria over time, averaged against the number of papers in each time range. Criteria with a significant relationship to year of publication at the $p < 0.05$ level are indicated

Table 1 Correlation between year of publication and the best practice accessibility criteria (ns = non-significant). See Supplementary Material 3 for full details of accessibility criteria

Criterion	Correlation coefficient	Significance (df = 23)
Open access %	0.633	$P < 0.001$
Accessible summary %	0.485	$P < 0.05$
Open data %	0.553	$P < 0.01$
Authors %	0.116	ns
Legislation %	-0.122	ns
Co-design %	-0.038	ns
Signposting %	-0.059	ns

particularly large numbers of papers (e.g. six in 2008, nine in 2021). There was also an increase in the use of some accessibility criteria in the body of work over time (Fig. 3). There was a significant relationship between year of publication and the meeting of criteria of freely accessible publication, freely accessible data and accessible summary (Table 1). There was no significant relationship between year of publication and co-authorship, legislative tie-in, co-design or signposting.

Table 2 Accessibility criteria vs conservation-value scores; bold figures indicate those criteria which were relevant to the extracts reviewed by practitioners

Criteria	Yes	No	Difference between y/n
Open Access	3.65 (23)	3.36 (22)	0.29
Plain language summary	4.25 (4)	3.46 (56)	0.79
Open Data	3.75 (8)	3.46 (41)	0.29
Co author	3.84 (19)	3.36 (41)	0.48
Co design	3.95 (21)	3.26 (39)	0.70
Legislation	3.90 (22)	3.30 (38)	0.60
Signposting	3.69 (38)	3.20 (22)	0.49

Value to practitioners

Approximately half (51.7%) of extracts had median scores of ≥ 4 , with 31.7% scoring between 3–3.9 and 15% scoring between 2 and 2.9. Only 1.7% scored < 2 . There was no significant relationship between the average score and year of publication. The highest average rating was for 2015 and the lowest for 1995, but there was a relatively consistent range of scores across the entire time period, with $> 50\%$ of values at between 3 and 4. When accessibility criteria were cross-referenced with extract conservation-value

scores, there was an indication that papers which employed the criteria scored higher on average (Table 2). The difference between the average score for the papers which did and did not adhere to each criterion was largest for accessible summaries (0.79), co-design (0.7) and legislative tie-in (0.6). Table 2 includes all criteria for completeness, but only those which have relevance to the actual extracts as reviewed by practitioners have been highlighted. Other criteria were either not known to participants (such as open access status) or did not have a bearing on the content of the text they reviewed.

During thematic coding of practitioner responses, three themes were examined: *usefulness*, *clarity* and *practicality*, and positive and negative comments were extracted from each. Usefulness was the most frequently discussed theme, followed by clarity and then practicality. Usefulness had many more positive than negative comments, whilst clarity also had more positive comments but by a much smaller margin. Practicality was the only theme in which there were more negative than positive reflections. When tested for association between median scores and frequency of each code, results from contingency tables (Chi-square tests) showed that counts of negative comments about clarity were associated with low scores and conversely, counts of positive comments were associated with higher scores ($X^2=37.42$; $df=2$; $p<0.01$). Similarly, counts of negative comments about usefulness were associated with lower scores, whilst counts of positive comments were associated with higher scores ($X^2=33.49$; $df=3$; $p<0.01$). No conclusions could be drawn about practicality and the scoring, due to the low numbers of comments referencing it.

Discussion

Are we “practicing what we preach”?

The accessibility criteria used in this study are widely agreed in knowledge-exchange literature to be important for improving the communication of academic work to conservation practitioners (Sunderland et al. 2009; Fuller et al. 2014). Indeed, many palaeo-researchers who have written on the research-implementation gap between palaeolimnology and conservation practice have recognised these approaches as

being of high value (Saulnier-Talbot 2015). What is clear, however, from this review is that even amongst what would represent the most relevant applied work, most of these approaches are poorly represented, with only the signposting criterion being present in more than half of the papers reviewed. The increased usage of select accessibility criteria (freely accessible, accessible data, accessible summaries) over time is likely reflective of changing publishing norms towards more open research practices. Tellingly, several key accessibility criteria reflective of co-production showed no significant increase (co-authorship, co-design, legislative tie-in), despite the increasing body of literature advocating for them against a backdrop of a building momentum towards better integrated research and practice (Cadotte et al. 2020).

That being said, there was an increase in the number of articles over time that passed the screening criteria for the study, suggesting that at least more research is being carried out that seeks to be relevant to practice. This must, however, be viewed with the caveat that there are more articles being published in general resulting from “publish or perish” mentalities (Hanson et al. 2023). A total of 35% of papers from the initial search were retained after screening against Conservation Evidence inclusion criteria. This was much higher than the 10.8% retention rate of ‘action’ studies reported by Groff et al. (2023) (i.e. studies which contained “*a discussion about the implementation of a conservation, restoration, or management action*”), suggesting that, among the broader conservation–palaeobiology literature, palaeolimnology has succeeded in becoming better integrated into conservation practice than other strands of the discipline. This is likely a result of stimulation of lake research by the EU WFD (mentioned by six studies), which highlights the importance of integrating palaeolimnology into conservation policy. Indeed, 37% of papers made reference to some form of conservation legislation.

Accessible summaries were the least common technique employed amongst the papers assessed. Only two of the 60 articles examined had graphical abstracts and only two included implications for practice sections, with the latter appearing to be related to the journal requirements (*Restoration Ecology*). There were no papers in this study which used plain language summaries. Whilst authors have some agency in this, enforcement of good practice by the

journals themselves is key to improving accessibility. There are good examples of journals that already do this. For example, the British Ecological Society journal named *Functional Ecology* asks all authors to write plain language summaries of their papers to make the research more accessible, this being published as an accompanying blog. A recent article in the journal which employed palaeoecological techniques provides a good example of how this could be done for applied palaeolimnological research (Brown et al. 2023). Other journals have also begun to use video abstracts to improve communication of the published studies and to connect with new audiences, but additional time, contacts and resources for researchers are required to do this effectively (Ferreira et al. 2023). The importance of clear language in explaining results in an accessible way to practitioners is further discussed below, but creation of accessible summaries is an ‘easy win’ for better communication.

With regard to open research principles, fewer than half of the articles could be freely accessed online through journals themselves (38.3%), whilst an additional 25% were available via third party research repositories. Whilst for a conservation practitioner it likely makes no difference which website is used to access the paper, this finding highlights the onus placed on researchers to increase the accessibility of their work through websites such as ResearchGate. Journals play a key role in supporting access to information for practitioners and, whilst it remains an issue, there has been positive development through the advent of new journals with open access, application-focused publications such as *Ecological Solutions and Evidence* (Cadotte et al. 2020), as well as shifts towards open research in older journals. Provision of easily useable open data was also limited in the selection of papers in this study. Many of those that did offer data in their supplementary materials were not in a format that would be easy to interrogate or utilise. For example, instead of providing raw data in spreadsheet format, many provided non-editable PDFs of tables and additional graphs in the supplementary materials, or simply stated that data could be provided on request. This is in contradiction to Open Data guidance (Dietrich et al. 2012), which recommends that data should be provided “*in a convenient and modifiable form*”. This, however, should also be viewed with the caveat that many older articles in this study were likely not expected (or able) to provide

supplementary data with their publication, due to changes in the standard practices in journal publications. It is worth keeping resources, such as the Open Data guidance, in mind when preparing for publication, to ensure practitioners are able to access underlying data if required.

The co-production of knowledge is increasingly recognised among palaeo-researchers as a key way to generate more applied and impactful research (Dietl et al. 2023). This review suggests that this occurs to a limited extent in palaeolimnology, though some organisations have clearly been engaged in the research (e.g. *Natural Resources Wales* formerly *Countryside Council for Wales*) and have both commissioned and co-produced several papers in this study. Nonetheless, palaeolimnology in comparison to the broader picture of practitioner-researcher co-production in conservation literature, does well. A comparable study focusing on the effectiveness of conservation interventions examined practitioner collaboration and found that only 21% of the sampled 2019 publications included practitioners as named authors, whilst 31.7% of the papers reviewed here were co-authored (Tinsley-Marshall et al. 2022). There are, however, mixed findings regarding the usefulness of co-authorship and affiliation lists as a method to understand the extent to which the research was co-produced by academics and practitioners. Whilst it has been used as a metric in comparable studies, the degree to which it reflects collaboration has been disputed (Hogg et al. 2018). Some argue that scientific output does not accurately reflect the design of research programmes and, as such, non-academic partnerships are often poorly reflected in author affiliations (Koier and Horlings 2015). Indeed, Groff et al. (2023) reported that several surveyed authors cited co-design of research despite this not being clear from the publication itself, and thus co-authorship as a metric may underestimate the extent of collaboration. Conversely, Tinsley-Marshall et al. (2022) argue that co-authorship likely overestimates collaboration due to the multiple affiliations of many practitioner authors with research institutions beyond the conservation bodies. As there is clearly contention around the visibility of practitioner-researcher partnerships based on author listings in academic outputs, the findings must be viewed with this caveat, but the findings nevertheless suggest that there is scope for greater collaboration at the publication stage

between palaeolimnologists and those that their work is intended to inform.

Does “practicing what we preach” equate to a valuable and relevant applied paper?

Whilst the accessibility criteria interrogate each paper as a whole entity, the practitioners evaluated only an extract containing the recommendations. Clearly, some criteria are not relevant to the extract of the paper that was reviewed, such as open access and open data, as these were effectively bypassed for the practitioners conducting the reviews. Papers being freely accessible with accessible data are obviously beneficial for the actual accessibility of a paper, especially for non-institutionally affiliated researchers or conservation practitioners. However, simply following open research practices does not inherently make an article well-expressed or of value to practitioners, as noted by Roche et al. (2022) in their statement that “*making knowledge available does not necessarily make it interpretable*”. Indeed, conservation recommendations from palaeoecological work are often poorly articulated (Kelley et al. 2018). In terms of examining the interpretability of the work, the most relevant criteria are legislative tie-in, co-authorship and co-design, as these directly relate to the content and expression of the text. The results suggest that authors who met these criteria produced work that practitioners ascribed a higher value to. As discussed above, there is contention around the discernability of collaborative research efforts from academic papers, but nevertheless a relationship between higher scoring papers and those which were visibly co-produced does appear to be present. The link to legislative tie-in is not surprising, given that incorporating complementary disciplines and inter-disciplinary evidence, such as palaeolimnology, into conservation policy has been identified as a key mechanism to develop integration (Young et al. 2014; Cook and Sgrò 2017). Indeed, a similar exercise to that undertaken by Cook and Sgrò (2017) in the field of Evolutionary Biology could be of great benefit to identifying key areas where palaeolimnology could improve engagement with policy. The above points emphasise the importance of co-production of knowledge and situation of work within a conservation context.

Interestingly, the average paper score did not show any substantial improvement over time, suggesting

that while palaeoecologists have striven towards producing more integrated and applied work, this has not translated into papers becoming more valuable for practitioners. This may be a reflection of the fact that, whilst the research community has vocally identified these issues, there is still a lack of cross-disciplinary training to equip palaeo-scientists for working in conservation contexts, and for gaining a full understanding of management and policy (Kelley and Dietl 2022). The results also highlight the value of papers across all years, showing that value and relevance does not conversely depreciate with time. Indeed, some of the pre-2000 studies in the selection were among those scoring highest among practitioners (Hodgson et al. 1998; Chambers 1999). Unfortunately, many pre-2000 academic papers were not published under open access, preventing many practitioners from accessing these valuable resources (Laakso et al. 2011). This was the case with the articles in this study, with the first officially open access study being from 2007, and none of the pre-2000 articles being accessible via third party repositories. The poor access to older literature has been slowly improving through “backfilling” (authors self-archiving older articles), and should be considered by palaeolimnologists to improve the visibility of work where appropriate under journal-copyright agreements (Piwowar et al. 2018).

What works for the practitioners?

In theory, given the selection criteria, all of the papers included in this study should provide useful conclusions and recommendations for conservation practitioners. In particular, papers praised for their clarity and usefulness scored higher, suggesting these factors were of key importance for practitioners.

There was, however, variation in the degree to which the findings were perceived as useful by the practitioners, and there are some key lessons to be learned from this. Papers where reference was made to clearly actionable recommendations were received well. The respondents valued “*solutions-focused*” work, especially where multiple options for management or restoration were compared as alternatives, or where habitat or species-specific advice was given. Thematically, many of the favoured recommendations were about understanding the past natural state of sites and species distributions, and where caution

should be exercised before conservation actions are taken. Whilst many papers were lauded for their valuable insights, a large number were criticised for not providing clear guidelines or actionable suggestions of what to do with their conclusions. Several respondents described the “*generic and obvious*” suggestions provided by some of the papers, speaking to two key issues. Firstly, that researchers were not always au-fait with what is common knowledge and practice among the group they are speaking to, which was perceived as “*arrogant*” and “*naïve*” by respondents. Secondly, that many of the recommendations are out-of-date and “*lacking detail of modern management practices*”, which mirrors problems in the broader context of evidence-based conservation practice (Hunter et al. 2021). There was an obvious alienation of the practitioners in cases where they felt their knowledge and work was perceived to be simplistic. It would be beneficial for the recommendations made by researchers to be grounded and situated in current conservation practice, which in turn would be facilitated by greater collaboration with practitioners. In addition, papers that primarily concluded that further research was needed were seen to be ultimately frustrating for many practitioners, being called “*the kind of conclusion you hate as a land manager*”. This self-perpetuating feedback loop of needing more research does not benefit practitioners, who are left without concrete answers to their queries. There is an important line to tread between ensuring that conclusions are made robustly and the never-ending pursuit of additional scientific knowledge under the assumption that it will always benefit conservation (Ehrenfeld 2000).

One of the most commonly-voiced frustrations was the use of “*over-technical and inaccessible*” vocabulary which often made the advice “*hard to digest*” and led to the key messages of the study being “*very hard to understand*”. Given the unfamiliarity of the average conservation practitioner with technical palaeo-jargon, it is no surprise that the language used in many of these papers was off-putting and prohibitive for use, as has been discussed previously by many authors (Bjune et al. 2015; Clarke and Lynch 2016). Comparatively, there was clear appreciation for those papers that stated findings in a “*simpler and clearer*” and “*easy to follow*” manner which allowed them to “*understand what they mean in practical terms*”. One paper (Bennion et al. 2024) in particular, was lauded by multiple respondents for its use of

a decision-making flowchart, which was described as “*gold*”. Use of bullet pointed recommendations in another paper was also praised (Salgado et al. 2023). These relatively simple and succinct forms of communication could be more widely implemented in applied palaeolimnology publications to help reduce the length and complexity of text, and avoid being, as one participant put it, “*academic for academics sake*”. Given that lack of time is also a commonly cited factor preventing practitioner engagement within research, the simpler a message can be conveyed, the better (Fabian et al. 2019). This is also true for figures and graphs used to present palaeoecological data. Anecdotally, stratigraphic plots have been described as unfamiliar and difficult to interpret for non-specialists, and researchers should consider alternative graphical formats to improve visual literacy of their research. There are many examples of data-presentation options to improve the interpretability of palaeo-figures; such as plotting time on the X (rather than Y) axis (McGowan, pers. comm.), combining multiple variables into a single metric (Lin et al. 2019) or spatially presenting results at a catchment level (Moorhouse et al. 2018). The presentation of evidence in broader conservation literature is discussed by Downey et al. (2022), who highlight the varied options for the production of evidence-based guidance for conservation practitioners. In particular, they recommend creation of additional user-friendly documents alongside technical reports, as well as use of existing frameworks for producing guidance. These discussions are becoming more commonplace in ecological research, due in part to the work of Conservation Evidence, and clearly also have a place in palaeolimnological research.

Another key theme was a lack of consideration for practical constraints on practitioners, though mentioned fewer times than clarity and usefulness, and how these would ultimately determine their ability to implement the management recommendations. One quote summarised the problem particularly well; that there was “*no point suggesting solutions if the likelihood of achieving them is zero*”. Where practical considerations were referred to by respondents, financial cost was commonly cited as a poorly considered factor. Those studies which did discuss cost implications were appreciated for doing so, as they enabled practitioners to “*produce a plan to cost appropriately*”, although these were in the minority and were only

mentioned in two extracts. Financial pressures on the conservation sector routinely dictate which management decisions are made, and funding often falls short of what is necessary to ensure optimal biodiversity outcomes (McCarthy et al. 2012). Cost implications have been shown to be poorly documented in academic literature reporting on conservation interventions more broadly, suggesting that this problem is not unique to applied palaeolimnological research (White et al. 2022). Echoing the recommendations made by White et al. (2022), it is clear from the responses that practitioners would have appreciated “*finer details*” of costs in order to understand how affordable the recommendations (commonly cited as “*sounding expensive*”) were for them to implement. For palaeoecological research, this is of particular importance given the perceptions of the science as prohibitively costly and lengthy (Saulnier-Talbot 2015; Siggery et al. 2023). It was clear throughout the commentary that practitioners resonated with those papers that demonstrated “*empathy with decision-maker’s quandary and responsibilities*” and the complex nature of managing multiple stakeholders, project timescales, equipment, and materials. Interestingly, many of the papers that were highlighted as having good practical considerations were co-authored by individuals from conservation organisations, and had evidence of the research being co-designed by practitioners. This highlights the importance of collaborative working between researchers and intended end users of palaeolimnological research in knowledge production.

Conclusions

This article has highlighted the value of palaeolimnology to conservation practitioners and has identified pathways for the continued improvement of this dialogue. Of all the themes discussed, that which is most fundamental to producing high-quality applied research is the co-production of knowledge and embedding of conservation practitioners in all stages of research production. Indeed, co-production is likely fundamental to achieving many other recommendations made in this paper, such as greater consideration of practicality and improved placement of research within conservation contexts. Collaboration is shown to be key to accessing contextual knowledge around management practices and conservation

policy, and to ensuring that researchers are not left in unfamiliar territory where uninformed recommendations can potentially alienate practitioners.

Through an examination of the successes and pitfalls of previous research efforts, this paper makes several recommendations to help elevate applied palaeolimnological research to a ‘gold standard’. The five recommendations for palaeolimnologists to improve the accessibility and value of their works to conservation practitioners are as follows:

1. Situate conservation recommendations within existing practice and knowledge. Take time to understand what standard practice/knowledge is and how findings can be complementary to this.
2. Consider the practicalities for practitioners of implementing the recommendations made. This includes both in terms of material aspects (cost, equipment) as well as the socio-economic context (policy, stakeholders).
3. Use clear and simple vocabulary and expression throughout, without assumptions of prior technical knowledge or unnecessary acronyms, and resisting excess verbosity.
4. Use clear, easy to interpret summative or synthesis diagrams and bullet pointed recommendations in plain language, in an explicitly designated section of the paper.
5. Make older (and newer) work available through online repositories, where appropriate, so that practitioners can access valuable pieces of work which may be of high local and contextual relevance.

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Data availability The full data that support the findings of this study are not openly available due to reasons of anonymity and are available from the corresponding author upon reasonable request.

Declarations

Competing interests H.B. is an associate editor of the Journal of Paleolimnology at the time of submission.

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