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Practitioner perspectives on the application of palaeoecology in nature conservation

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It is widely recognised that palaeoecology holds great potential to inform and support nature conservation, but that there are difficulties in knowledge exchange between academia and practitioners that inhibit the operationalisation of research. To facilitate the integration of palaeoecology into the conservation toolkit, it is essential to understand perspectives of the practitioners themselves and the contexts in which they work. This paper reports the results of a survey of 153 UK-based conservation practitioners, concerning their perceptions of palaeoecology, the barriers to its use and potential solutions for making palaeoecological insights more accessible in conservation practice. The survey was conducted online over a period of 3 months; closed question responses were analysed for statistical trends and thematic analysis was done on open question responses. The majority of respondents were strongly positive about the role palaeoecological research could play, though they also exhibited a limited understanding of how and why one might implement it. They identified time constraints as the biggest barrier to using palaeoecology within their work, and also flagged concerns around financial resources and the accessibility of the research. Access to applied case studies and a centralised database were the most favoured solutions among respondents. Respondents with prior experience of working with palaeoecology were generally more optimistic about its incorporation. This paper makes several key recommendations to progress the integration of palaeoecology into conservation, including improving data accessibility, aligning research design with conservation and policy drivers, and increasing both respective groups' understanding of the other.

KEYWORDS

conservation, palaeoecology, evidence based, practitioner, knowledge exchange, research implementation gap

1 Introduction

Global biodiversity loss poses a serious threat to resilience of the biosphere to cope with climate change and to continue to provide essential ecosystem services to support human health, wellbeing, and prosperity (Naeem et al., 2016; Meyer et al., 2022). Whilst we are

now three years into the UN Decade on Ecosystem Restoration (2021–2030), conservation efforts continue to struggle to keep pace with the rapid rate of species loss and environmental decline (Isbell et al., 2023). The UK is one of the most nature-depleted countries in the world with a Biological Intactness Index of only 53% and has "lost" the last decade through failing almost all the Aichi Biodiversity Targets (RSPB, 2020; NHM, 2021). As a result, many are calling for systemic change and radical new approaches to be undertaken if we are to meet goals such as the Global Biodiversity Framework "30 × 30" targets, adopted at COP15 in December 2022 (Travers et al., 2019; Convention on Biological Diversity, 2021). This urgency has been emphasised through recent analysis finding that a delay in action will rapidly increase recovery costs and make it infeasible to stabilise biodiversity loss (NHM and Vivid Economics, 2021). There is understandable pessimism around the ability of international governments to meet these targets, given the pressures on conservation practitioners in both the public and private sectors plus the experience of historic failures to meet biodiversity targets (Findlay, 2023). The UK signed up to the "30 × 30" targets in September 2020 (HM Government, 2020) but has made worryingly little progress towards achieving this, even undermining a science-led approach in some cases (Wildlife and Countryside Link, 2022). Science and evidence have a clear role to play in the achievement of the UK's "30 × 30" biodiversity targets in supporting governance, decision-making and target setting (Gnacadja and Vidal, 2022).

One of the key challenges faced by conservationists is a lack of applied research and evidence to inform evidence-based decision making (Jarvis et al., 2020). There is a "knowledge–doing" gap across many scientific disciplines, but a particular challenge for conservation science is the lack of formally structured and funded evidence "bridges" (Kadykalo et al., 2021). This is a complex issue to unpick; there are a myriad of pressures on academics, several of which drive their research away from practitioner collaboration, not least the pressure to publish in high impact academic journals, particularly for early career researchers. These high impact journals are written for and reviewed by academics – not practitioners – and are additionally not where the research is likely to be found by the average conservation practitioner. Conservation practitioners are key players in delivering habitat creation, management and restoration, and are defined in the context of this paper as professionals working across conservation charities (e.g., The Wildlife Trusts, RSPB), local and national government regulatory bodies (e.g., Environment Agency, Natural England), as well as in private consultancy. Allegations of "evidence complacency" have been levelled at practitioners, although this is recognised to be a relatively complex issue, with nuances around multiple factors including funding, accessibility to evidence, as well as mis-interpreted relevance, rather than being a simple "attitude problem" (Sutherland and Wordley, 2017; Christie et al., 2020; Tinsley-Marshall et al., 2022). Practitioners are nevertheless alert to the issue and are keen to improve their use of evidence, exemplified by a recent internal study conducted by The Wildlife Trusts (one of the largest UK conservation NGOs) which found that whilst 80% of Trusts recognised the value of evidence-based conservation, only 13% felt they could confidently say they were practicing it (Parry et al., 2022). There is now more pressure on researchers to increase the relevance and impact of their work in order to improve knowledge exchange, for example through initiatives such as the Conservation Evidence database (Sutherland et al., 2019). Despite steps in the right direction, practitioners remain largely disconnected from the academic community and there remains the need for solutions to help close this gap (Fabian et al., 2019).

Palaeoecology has the potential to provide a novel toolkit to inform conservation science and policy. It provides a unique mechanism for better understanding the temporal dynamics of ecosystems and biological communities, is less sporadic and anecdotal than historical surveys, maps and photographs, and is applicable not only on deep-time scales, but also on centennial and even decadal scales (Birks, 2019b). Over the last 20 years, in particular, there has been an expansion in the recognition of palaeoecology and palaeobiology as applied sciences with a role in supporting conservation, both theoretically and also in a more practical sense, through habitat management and restoration (Dillon et al., 2022). There is a wide and growing body of applied palaeoecological work, ranging from assessments of historic distribution of locally extinct priority conservation species (Bishop et al., 2019), to the creation of evidence-based lake management plans from palaeolimnological reference conditions (Sayer et al., 2012). Palaeoecology has been used to support conservation efforts in many different biomes around the globe, such as Mediterranean forests (Piovesan et al., 2018) African grasslands (Gillson, 2021) and tropical peatlands (Ramdzan et al., 2022). Within the UK conservation context, there is already a well-established role for palaeoecology in addressing environmental challenges. One of the most prominent successes of this is the use of diatom-inferred pH transfer function models, to evidence the acidification of freshwater lakes and prove a causal link between anthropogenic fossil fuel combustion and freshwater acidification (Battarbee et al., 2014). On a smaller scale, there are also examples of palaeoecological studies that assess the perceived naturalness of National Nature Reserves (Oldfield, 1970), reconstruct land-use histories and their impact on rare flora (Edwards, 1986), support historical peatland management practices (Blundell and Holden, 2015) and assess the condition of Sites of Special Scientific Interest (SSSIs) in relation to their EU Water Framework Directive targets (Bennion et al., 2005; Bennion and Battarbee, 2007). Post-Brexit UK legislation has to date, had little to no interaction with palaeoecological research, yet there is a pressing need for additional temporal insight on ecosystem dynamics and resilience thresholds as earth systems move into no-analogue conditions (Fordham et al., 2016). Additionally, there remain pertinent questions around the potential of palaeoecology to assist conservation and restoration in the light of unprecedented climate and land use change.

The ability of palaeoecology to address a breadth of conservation challenges is well known amongst prominent researchers in this field, a synthesis of which was produced by Seddon et al.'s (2014) influential paper outlining the priority questions for palaeoecological research. There is, however, a recognised issue with the accessibility of palaeoecological work to practitioners, which has been highlighted by both the research and practitioner communities (Rull, 2010; Anderson, 2014).

Similar to many other scientific disciplines, alluded to already, this accessibility issue is both physical in terms of research published in journals behind paywalls, but also in a less direct vein due to a lack in mechanisms to facilitate attention to, and thus operationalisation of, the research by intended end users. There is also a need for more informed consideration in research design to better relate it to practitioners, as well as improved reach in communication of research outputs beyond academic journals (Clarke and Lynch, 2016; Birks, 2019a). Dillon et al. (2022) survey of 196 professionals, was particularly revealing on this matter, with 38% respondents feeling that the field was applied but with only 19% consistently collaborating with non-academic stakeholders. This study also reflected a prevalence for these feelings internationally as 36 countries were represented in the responses. Some barriers are more specific to palaeoecology, with some authors citing the issues caused by arbitrary psychological divisions between past and present, whilst others have cited general misconceptions around the role and utility of palaeoecology (Davies and Bunting, 2010; Rull, 2014). There are also communication barriers connected with the unavoidable use of technical terminology and hence an appropriate choice of journal, as conservation practitioners are more likely to read and understand contemporary ecology articles published in ecology or conservation bulletins and periodicals. Recent progress has been made towards understanding the best mechanisms to address this disconnect, but there remains a need to consult with practitioners to progress the internalisation and subsequent application of palaeoecological research by conservationists (Aquino and De Castro, 2017; Groff et al., 2023). Palaeoecology has been applied successfully, albeit to a limited extent, to support conservation work in the UK, resulting in at least some practitioners with prior experience working with palaeoecological research. As those with prior experience should have a better understanding of how palaeoecology might be applied, and what the challenges for doing so might be, these practitioners are logically the most insightful to be consulted.

This paper aims to improve the understanding of how palaeoecological insights may be better operationalised, by investigating the perceptions of palaeoecology amongst conservation practitioners, in order to address the gap in data most recently highlighted by Groff et al. (2023). Whilst this remains an internationally pertinent question, the scope of this paper is based on professionals in the UK, where there has already been some notable integration of palaeoecology into conservation practice, as described above. The research also includes initial findings on the significance of variables such as prior experience with palaeoecology by the conservation practitioner, on views about the practical use of palaeoecological knowledge.

2 Materials and methods

A self-completion survey employing a structured questionnaire was conducted amongst a sample of UK conservation practitioners, the key aim of which was to gather an understanding of their views on palaeoecology and its relevance within their context. The survey was conducted between March and May 2023 using the Qualtrics XM online platform (Qualtrics Inc, 2018).

An unstratified approach was taken to sampling, in order to capture a sample that could be considered representative of an anticipated diversity across the UK conservation sector and allow distribution to snowball through the community of practitioners. The survey was distributed through established networks of conservation practitioners, such as the internal Wildlife Trusts intranet platform, the CIEEM and ALGE newsletters, and local pan-sectoral bodies such as the Surrey (local) Nature Partnership. This facilitated the capture of the views from a variety of professionals across local government, private consultancy and environmental NGOs. To ensure that practitioners with experience of palaeoecology were represented in the sample, additional purposive sampling was conducted by approaching individuals who are known to have used applied palaeoecology in a UK conservation context.

A variety of open and closed question styles were used for the questionnaire in order to provide scope for both quantitative and qualitative analyses of the responses, whilst also balancing participant motivation with the capture of more nuanced responses (Yates, 2003). The opening questions collected information on participants work profiles, including their job profiles, length of time in the sector, responsibilities and broad habitat types worked with as per the UK Habitat Classification. The subsequent questions fell into four broad categories:

i. **Prior knowledge and experience of palaeoecology.** Participants were asked about their understanding and experience of palaeoecology in a conservation context and were asked to supply a definition in their own words.
ii. **Potential uses of palaeoecology within conservation.** Respondents were asked to rate varying suggested applications of palaeoecology to conservation work as either "helpful"/"could be helpful"/"not helpful". These were drawn from a mixture of established applications of palaeoecology (e.g., setting restoration targets, as for the EU Water Framework Directive; Carvalho et al., 2019), and applications that could have relevance for certain concepts and policy drivers for practitioners, such as valuation of ecosystem services (UK National Ecosystem Assessment, 2011) and natural capital (Barbier, 2019).
iii. **Barriers to operationalising palaeoecological knowledge**. Respondents were invited to rank some suggested barriers in order of importance. The barriers in the questionnaire were based on barriers established by previous work on the "knowledge–doing" gap between conservation and palaeoecological research (Rull, 2010; Saulnier-Talbot, 2015).
iv. **Suggested solutions to improve the accessibility of palaeoecology for conservation practitioners.** Respondents were asked to rank suggested solutions on a scale of importance. Selection was largely based on suggestions in previous reviews (Goodenough and Webb, 2022) but also on contextual knowledge of well-used conservation toolkits, e.g., GIS platforms.

The full questionnaire can be found in Supplementary Materials 1. Data was exported from Qualtrics XM in.xlsx format and cleaned (removal of metadata, formatting of data for statistical analysis) in Microsoft Excel prior to analysis. Full survey responses can be found in Supplementary Materials 2.

Closed question responses were analysed quantitatively, using descriptive statistics and plots generated using SPSS v.28.0 (IBM Corp, 2022). Due to the non-parametric nature of the ranking data, Kruskal-Wallis tests with *post-hoc* Dunn-Bonferroni tests were employed to identify patterns in responses and create subgroups for their categorisation. Additionally, Mann-Whitney U tests were used to explore associations between responses and respondents for the disaggregate of experience Chi-Square tests were also used to explore counts of responses when variables were non-ordinal.

Open question responses were analysed manually via a thematic analysis approach in NVivo v1.7.1 (Lumivero, 2022), systematically exploring key terms and themes in responses (Braun and Clarke, 2006). For analysis of definitions, a keyword identification approach was taken, where each response was scanned for synonymous keywords and phrases that indicated understanding of a particular aspect of palaeoecology. For example, to indicate understanding that palaeoecology related to the past, keywords and phrases including "past", "ancient", "prehistoric", "before modern records", and also mention of specific time periods such as "Pleistocene" or "Jurassic". Other open responses were analysed in a similar fashion and grouped into thematic categories to identify common trends in responses. The full statistical outputs and thematic analysis are given in Supplementary Materials 3, 4.

3 Results

At the end of the survey period 153 responses were received, all responses were included in the data analysis. Responses were received from professionals at a variety of career stages, with the largest group being at an operative level, including job titles such as "officer", "advisor" and "ecologist" (Table 1A). Participants reported working in different subdivisions within the conservation sector, with the largest cohort being from environmental NGOs, such as The Wildlife Trusts, the RSPB and the National Trust (Table 1B). There was also a spread of respondents with different lengths of service within the conservation sector, with the majority either long-term employees (15+ years) or early career (0–5 years), (Table 1A). Geographic information was not collected from respondents, and thus no assertions can be made about the representation from each of the devolved UK territories, which have varying statutory conservation bodies and legislations. Of the job responsibilities identified by the participants, "surveying species and habitats" was the most common (56%), followed by "delivering practical conservation and land management" (45%) and "advisory role" (40%). When asked about the main habitat types they worked with, "woodlands, ancient and semi-natural" was the most common (68%), followed by "neutral and calcareous grasslands" (61%) and "standing open waters and rivers" (52%). The least common were "upland and montane" (7%) and "coastal, saltmarsh and marine" (14%).

3.1 Knowledge of palaeoecology

When questioned on their pre-existing knowledge of palaeoecology, 83% of respondents had heard the term before, though only 41% felt they had a confident understanding of it. Those who had come across the term before were then requested to provide a definition in their own words and 123 responses were recorded from 80.4% of participants. Nearly all responses reflected an understanding of the ecological or environmental aspects of palaeoecology (n=121; 98.4%) and the relationship to the past (n=120; 97.6%). Of those who specified beyond a vague concept of "the past" or "history", 20 respondents associated palaeoecology exclusively with "deep-time" and only one expressed an understanding of its utility across a range of timescales. A range of methods for conducting palaeoecological research were mentioned by respondents, with use of fossils or remains (n=32; 26%) being the most frequently cited. There were 15 mentions of the use of sediment/soil cores, and two mentions of dating methods. With regards to specific indicators, the most frequently mentioned was pollen (n=17; 13.8%), with diatoms and isotope ratios being mentioned only once respectively. There was also mention of indicators not typically associated with palaeoecology, including "ancient DNA" and "geomorphological features". A relatively small pool of respondents discussed the application of palaeoecology as part of their definition

TABLE 1A Breakdown of respondents by career level and length of service.

Career level:	Junior	Operative	Management	Senior
% respondents	14%	38%	28%	20%
Time in sector (years):	0–5	5–10	10–15	15+
% respondents	34%	16%	12%	38%

TABLE 1B Breakdown of respondents by sub-sector of the conservation sector.

Sub-sector:	Environmental NGO	Local government	Statutory body	Private & consultancy	Other
% respondents	58%	13%	6%	19%	4%

(*n*=27; 22%). Most frequently the general notion of determining past species assemblages and/or past site conditions was expressed, though only one respondent used the term "baseline". Regarding specific applications, the role of informing land management and practical conservation was cited by seven respondents. There were only very few (*n*=3; 2.4%) mentions of the potential for palaeoecology to inform understanding of future ecosystem dynamics and management approaches.

Only 26% of respondents stated that they had experience of working with palaeoecological research. There was a significant association between length of service and exposure to palaeoecological research, with those working in the sector for over 15 years more likely to have experience with palaeoecology (X^2=12.53; df=3; p<0.01). Additionally, those in more senior roles more frequently had experience of working with palaeoecology than those in more junior roles (X^2=11.64; df=3; p<0.01). With regards to habitat types, those with palaeoecological experience were more likely to have worked with wetlands (including fens, bogs and grazing marsh) (X^2=9.44; df=1; p<0.01), but there was no association between experience and any other habitat type.

3.2 Potential uses of palaeoecology

An independent-samples Kruskal-Wallis test found that there was a significant difference between rating the "helpfulness" of different uses of palaeoecology by respondents (H=73.59; df=6; p<0.01), with mean rating scores displayed in Figure 1. Additionally, a Dunn-Bonferroni *post-hoc* test for homogeneous subsets was conducted to identify significant differences between the rating of each use (Figure 1). Uses have been paraphrased as described in Table 2.

TABLE 2 Proposed uses of palaeoecological research to aid conservation work.

Paraphrased for results	Proposed use in full, as seen by respondents
Past site condition	*Learning about past ecosystem condition*
Past species assemblage	*Knowing what species used to live in a site*
Natural state of site	*Establishing the natural state of an ecosystem*
Past management	*Informing about past management practices*
Restoration targets	*Setting restoration targets*
Ecosystem services	*Understanding past ecosystem service provision*
Natural capital	*Historic natural capital valuations*

The uses making up subgroup 1 ("Past site condition" (mean score 2.6) and "Past species assemblages" (mean score 2.6)) were viewed as the most useful to respondents. "Past species assemblages" also formed part of subgroup 2, alongside the "Natural state of a system" (mean score 2.5) and "Past management regimes" (mean score 2.4). This group was viewed as being more useful than the uses that fell into subgroup 3, but less so than subgroup 1, despite the overlap. The uses within subgroup 3 ("Ecosystem services", "Natural capital") was the lowest rated in terms of usefulness, but it should be noted that the range of mean rating of subgroup 3 was above 2 (score range from 2.3 to 2.2), indicating that the perception of them still skewed towards "helpful".

Responses were separated for those who stated they were "experienced" and "non-experienced" with palaeoecological research respectively. When compared with respondent experience of palaeoecology using a Mann-Whitney U test, only one potential use showed a significant difference between groups.

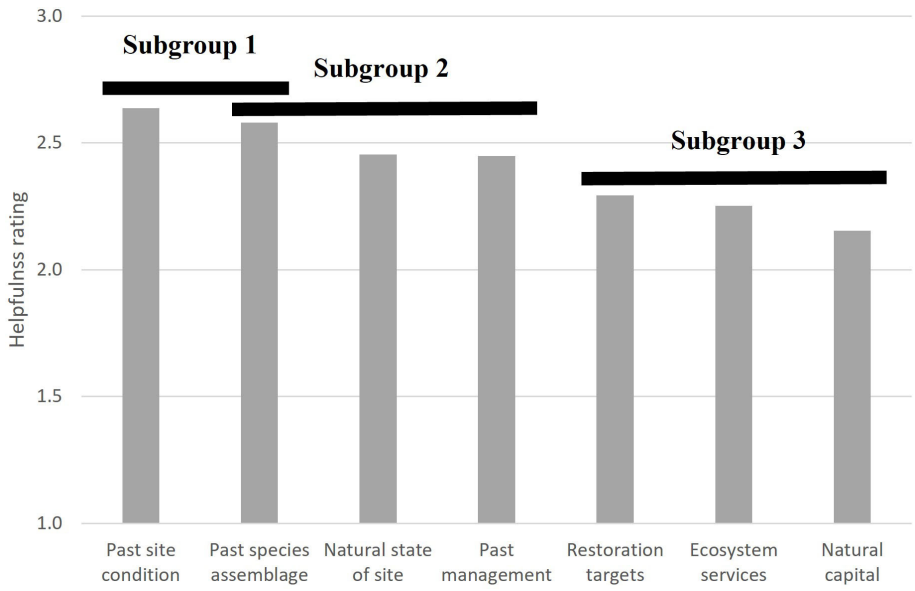

FIGURE 1
Mean rating of each potential use of palaeoecology, with 1 = "Not helpful", 2 = "Could be helpful", 3 = "Helpful". Black lines indicate statistically significant (at P<0.05) subgroups identified in the *post-hoc* Dunn-Bonferroni test.

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Those with experience rated the use of palaeoecology to look at "Past species assemblages" more highly than those without (z=2.67; p<0.01). In general, both experienced and non-experienced participants voted favourably for the utility of palaeoecology across a variety of suggested application scenarios (Table 3).

Experienced respondents were very positive and selected "helpful" or "could be helpful" in the vast majority of their responses across the seven applications (mean score 2.47); non-experienced participants were only slightly less positive (mean score 2.38) (Figure 2). In particular, experienced respondents felt that palaeoecology was helpful to look at "Past species assemblages" (mean score 2.78) and "Past condition" of a site (mean score 2.78); they were less certain about other uses but still considered it to be helpful for exploring "Past management" (mean score 2.49) and "Restoration targets" (mean score 2.38) and "Natural state of sites" (mean score 2.43). There was most uncertainty around the use of it for looking at "Ecosystem services" (mean score 2.24) and "Natural capital" (mean score 2.16) (Table 3).

The non-experienced group exhibited a very similar spread of responses to the experienced group, with a few exceptions. There was generally less confidence in the ability of palaeoecology to examine "Past species assemblages" and "Past site condition", as well as generally higher amounts of "not helpful" votes. Two applications scored a marginally higher "very helpful" vote; the use of palaeoecology to examine the "Natural state" of an ecosystem and historic "Natural capital" valuations (Figure 3).

Those who were non-experienced were asked an additional question of whether they were likely to use palaeoecology, having now considered the uses of it in the questionnaire. Participants were largely positive about the potential use of palaeoecology, with 72% of those who had not already done so saying that they definitely (44.3%) or probably would (27.3%) use palaeoecology in their work, while 23% were uncertain and 5% probably would not; only one respondent said they definitely would not.

3.3 Barriers to operationalisation

An independent-samples Kruskal-Wallis test found that there was a significant difference between the ranking of different barriers by respondents (H=353.17; df=7; p<0.01), with mean rank scores displayed in Figure 4. Additionally, a Dunn-Bonferroni *post-hoc* test

TABLE 3 Disaggregated mean rating of uses by respondent experience (experienced vs non-experienced) and Mann Whitney U results.

	Mean ratings				
	Overall	Non-experienced	Experienced	Test stat.	Significance
Past site condition	2.64	2.58	2.78	1.859	.063
Past species assemblage	2.58	2.51	2.78	2.67	.008
Natural state of site	2.45	2.46	2.43	−0.258	.796
Past management	2.45	2.43	2.49	0.304	.761
Restoration targets	2.29	2.26	2.38	0.877	.381
Ecosystem services	2.25	2.25	2.24	−0.07	.944
Natural capital	2.15	2.15	2.16	0.005	.996

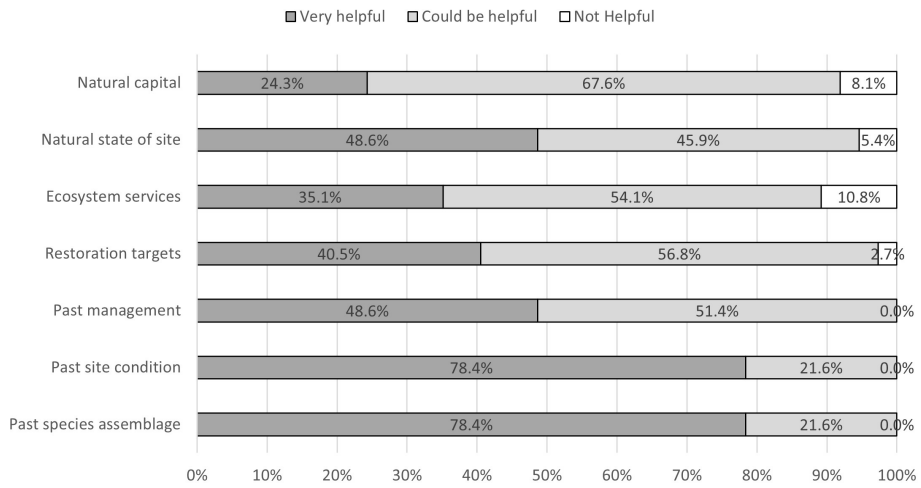

FIGURE 2
Responses of experienced participants on the potential uses of palaeoecology.

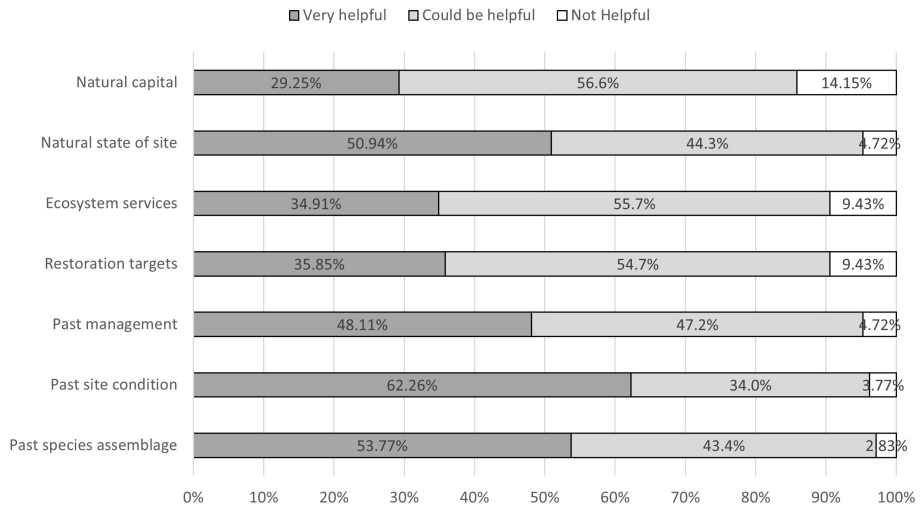

FIGURE 3
Responses of non-experienced participants on the potential uses of palaeoecology.

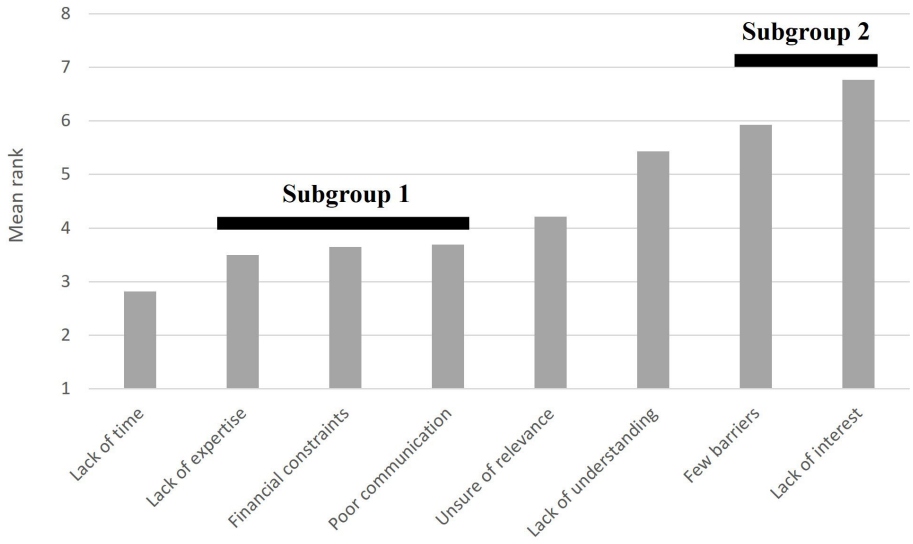

FIGURE 4
Mean rankings of barriers with black lines indicating statistically significant subgroups identified in a *post-hoc* Dunn-Bonferroni test.

for homogeneous subsets (cutoff was set at P<0.05) was conducted to identify significant differences between the ranking of each barrier (Figure 4). The highest ranked barrier to palaeoecology being better utilised by conservation practitioners was a "Lack of time" (mean score 2.8), and this was ranked significantly higher than any other barrier. The second highest ranked barriers were a statistically significant sub-group including "Lack of expertise" (mean score 3.5), "Financial constraints" (mean score 3.6) and "Poor communication" (mean score 3.7). These three were not significantly different from one another, but were, as a group, statistically ranked higher than all other barriers except "Lack of time". The lowest ranked barriers were in the second subgroup, which comprised of "Lack of interest" in palaeoecology (mean score 6.8) and the perception of there being "Few barriers" to application (mean score 5.9). Barriers have been paraphrased as described in Table 4.

A total of 50 respondents provided additional comment on this question, some of which reiterated the challenges of a "Lack of time" and "Financial constraints", as well as general accessibility. Other common themes raised included i) extensive land use change prevents authentic restoration; ii) relevance in light of climate change; iii) the findings and implications being "unpalatable" to decision-makers; and iv) a general lack of applied work and accessible information.

When responses with respect to barriers were compared for non-experienced and experienced respondents using a Mann-Whitney U test, two barriers exhibited a significant difference. Firstly, "Lack of understanding" was ranked more highly by non-experienced

TABLE 4 Suggested barriers of palaeoecological research to aiding conservation work.

Paraphrased for results	Proposed use in full, as seen by respondents
Lack of time	*Time constraints – We have limited staff resources and need to focus on our core responsibilities*
Lack of expertise	*Lack of expertise – We don't have anyone with expertise to interpret or implement this research*
Financial constraints	*Financial – We don't have the money to spend on things like this, it seems expensive*
Poor communication	*Communication – There needs to be better communication with the researchers doing this work, I'm not able to access publications*
Unsure of relevance	*Relevance – I understand the role it could play, but the results need to be expressed in terms that are relevant to me*
Lack of understanding	*Lack of understanding – I don't really understand how it would help, the language is inaccessible*
Lack of interest	*Lack of interest – I understand the role it could play, but I don't think it would be useful, I'm not interested*
Few barriers	*I perceive there to be few barriers*

participants (z=2.36; p=0.018). Additionally, those with experience ranked more highly the idea that there are "Few barriers" to implementing palaeoecological research (z=−2.69; p<0.01). Otherwise, the mean rankings largely agreed, for example "Lack of expertise" was ranked equally on average by both cohorts (Table 5).

3.4 Solutions to improve accessibility

An independent-samples Kruskal-Wallis test found that there was a significant difference between the ranking of different solutions by respondents (H=195.59; df=6; p<0.01), with mean rank scores displayed in Figure 5. Additionally, a Dunn-Bonferroni *post-hoc* test for homogenous subsets was conducted to identify significant differences between the ranking of each solution (Figure 5). The highest ranked solutions were those making up subgroup 1, which were statistically the joint highest ranked. This included the establishment of a "Centralised database" (mean rank 2.6) and the use of "Case studies" (mean rank=2.6). The majority of solutions were grouped in subgroup 2. The improved "Soft skills training" for researchers (5.1) stood out as the lowest ranked solution by the respondents. In general, there was a large spread of votes across different solutions, as indicated by the size of subgroup 2 and the relatively low range of mean ranks (2.5). Solutions have been paraphrased as described in Table 6.

Thirty-six respondents provided additional comment on this question, with several themes recurring between their answers; i) The solutions are all relevant and are linked; ii) Use of GIS; iii) Use of existing publications such as "In Practice" and "British Wildlife"; iv) Links to policy; and v) Training for practitioners.

When responses with respect to solutions were compared for non-experienced and experienced respondents using a Mann-Whitney U test, the only solution which exhibited a significant difference was the use of "Case studies", which was ranked more highly by non-experienced participants (z=−1.55; p=0.012). Otherwise, the mean rankings were largely in agreement between groups, for example "Soft skills training" was ranked equally on average, and use of "Specialist groups" was ranked very similarly (Table 7).

4 Discussion

That palaeoecology requires better integration into conservation practice is well-established from the perspective of palaeoecologists, and the findings of this study have demonstrated that this view is shared by the practitioners themselves (Vegas-Vilarrúbia et al., 2011). Almost three quarters of respondents who took part in the study did not have prior experience in palaeoecology but their thoughts on its utility largely mirrored those who did. This further supports the premise that conservationists are open and interested, but unable to readily access and/or deploy the palaeoecological research. The challenges and solutions highlighted by survey participants centre around the need for improvement of several key themes; i) understanding, ii) resources and iii) communication.

TABLE 5 Disaggregated mean ranking of barriers by respondent experience and Mann Whitney U results.

	Mean ranking				
	Overall	Non-experienced	Experienced	Test stat.	Significance
Lack of time	2.8	2.8	2.8	−0.132	.895
Lack of expertise	3.5	3.5	3.5	0.070	.944
Financial constraints	3.6	3.7	3.4	−0.769	.442
Poor communication	3.7	3.7	3.5	−0.524	.601
Unsure of relevance	4.2	4.0	4.8	1.608	.108
Lack of understanding	5.4	5.2	5.9	2.358	.018
Few barriers	5.9	6.2	5.1	−2.694	.007
Lack of interest	6.8	6.7	7.0	0.767	.443

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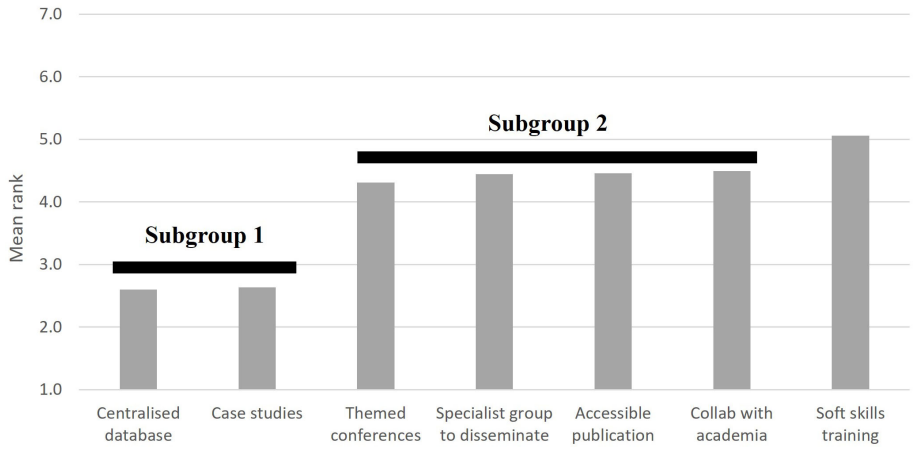

FIGURE 5
Mean ranking of solutions, black lines indicate statistically significant subgroups identified in the *post-hoc* Dunn-Bonferroni test.

TABLE 6 Suggested solutions to improve application of palaeoecological research to conservation work.

Paraphrased for results	Proposed use in full, as seen by respondents
Centralised database	*A centralised database of palaeoecological data which was accessible on online platforms like ArcOnline or Magic Map*
Case studies	*Case studies of palaeoecological research being applied in conservation management and restoration*
Themed conferences	*Themed conferences and working groups for palaeoecologists and conservation practitioners*
Specialist group to disseminate	*A specialist professional group which focused on disseminating applied palaeoecology research*
Accessible publication	*A publication which shared the research in accessible language*
Collab with academia	*Collaboration with academic institutions in project design and funding*
Soft skills training	*Better training of students and researchers in skills like project management and communication*

4.1 Understanding

Whilst nearly 80% of respondents were able to capture the essence of palaeoecology (i.e., relating to past environments) in their definitions, there were still a substantial number who had not heard the term prior to being approached about the survey and who felt unable to define it. The definitions submitted by respondents suggested that most practitioners had a basic understanding of the concept of palaeoecology, but few had a more detailed understanding of its methods and the purpose for its study. Fewer than half of the definitions included mention of palaeoecological methods, with only a single mention of diatoms despite their status as one of the most extensively used biological proxies in palaeoecological reconstructions (Mackay et al., 2003). Of particular note is a largely absent discussion of the applications of palaeoecology to conservation in the respondents" definitions, suggesting that they are unaware of its potential relevance to their work. Interestingly, when presented with potential applications in a subsequent question, there was an overwhelmingly positive response about the usefulness of palaeoecology. One respondent

TABLE 7 Disaggregated mean ranking of solutions by respondent experience (experienced vs non-experienced) and Mann Whitney U results.

	Mean ranking				
	Overall	Non-experienced	Experienced	Test stat.	Significance
Centralised database	2.6	2.5	2.8	0.905	.365
Case studies	2.6	2.4	3.2	2.506	0.012
Themed conferences	4.3	4.5	3.9	−1.553	0.12
Specialist group to disseminate	4.4	4.5	4.4	−0.283	0.777
Accessible publication	4.5	4.4	4.7	1.154	0.249
Collab with academia	4.5	4.7	4.0	−1.788	0.074
Soft skills training	5.1	5.1	5.0	0.113	0.91

stated that "*I would like to see more about the practical uses of palaeoecology. I have worked in land management for the past 40 years and not really seen much about it*". The responses captured in this survey clearly reflect a hunger amongst conservation practitioners to learn more how palaeoecology could support their work, but also a general lack of depth in understanding, for example, concerning the way a study could be conducted. This was reflected in the high ranking of "Lack of expertise" as a barrier, suggesting that participants were generally aware of their lack of understanding and recognised the impediment it may cause. It could be hypothesised that this disconnect is a result of a lack of exposure to the science, as several respondents expressed a desire for "*basic training courses on palaeoecology*" to be provided. A future study to examine the inclusion (or not) of palaeoecology across undergraduate degree programmes undertaken currently by those working in conservation, could shed significant light on this matter. Regardless of the causes, our study provides two key insights for palaeoecologists. Firstly, that care should be taken around assumptions of knowledge and use of technical language when working with practitioners and, secondly, that a lack of understanding does not equate to a lack of interest.

Whilst it could be assumed that those who lack understanding of the interface between palaeoecology and conservation are not the best placed to assess its usefulness, examination of the differences in responses between experienced and non-experienced practitioners paints a different picture. Experienced respondents were actually more positive about the utility of palaeoecology in conservation, particularly with regards to more well established and traditional uses of the science such as in assessing past species assemblages and site condition and management history. Both groups exhibited uncertainty in the role of palaeoecology to examine ecosystem services and natural capital, most likely because there remains a generally poor consensus about how these concepts are quantified and incorporated into contemporary conservation metrics, and indeed similar poor consensus around the metrics themselves (Birks, 2019a). This is compounded by the lack of precedent for applied palaeoecology in these realms, particularly for natural capital, and provides an interesting opportunity for researchers to explore novel applications. Existing palaeoecological work on ecosystem services (Dearing et al., 2012) has provided a model that could be expanded upon for greater application in a UK context alongside prospective alignment with policy guidance for practitioners. In addition, experienced participants ranked the perception of few barriers to operationalising palaeoecology higher than those without experience, again indicating that they were more positive about its use than non-experienced conservationists. They also ranked, somewhat predictably, "Lack of understanding" lower than the non-experienced group. The implication here is that understanding comes with exposure, as does the ability to see past other barriers. Other than this, there was largely agreement between the two groups with regards to the most important barriers, with resource-based barriers being ranked the most highly. These findings, rather than suggesting that the optimism of those without experience is naïve, reaffirm that there is an openness amongst conservationists for palaeoecology to support their work.

4.2 Resources

Resources, predictably, were highlighted as the main barrier for practitioners, with "Lack of time" emerging as the most significant factor, followed by "Financial constraints". There are perennial, ongoing funding pressures on the UK conservation sector, with public sector expenditure decreasing by 42% since 2008/9 (Hayhow et al., 2019). This leads, directly and indirectly, to the "Lack of time" experienced by conservation bodies (especially environmental NGOs) and the "financial" means for them, to fund or engage in scientific research. This follows a trend of segregating research and conservation in the UK, which began with the disaggregation of Natural Environmental Research Council (NERC) from the Nature Conservancy Council in the 1970s (Marren, 2002). Palaeoecology, as a lesser-known research avenue, is unlikely to become a priority for already scarce research funding. One comment by a participant working at a senior level captures this sentiment well; "*Unless funding changes dramatically, I doubt it"ll be used in more than a few key situations*". The funding environment for biodiversity conservation in the UK is currently in a particularly tumultuous phase. Crucially, Brexit has elevated uncertainty around the future of environmental grants for landowners to support for environmental protection in the UK (Gravey and Jordan, 2023). Equally, several novel financial mechanisms to support nature conservation in the UK remain untested to their full potential. One of these is Biodiversity Net Gain (BNG), which mandates developers to deliver a minimum 10% increase in biodiversity on new developments over a 30-year period. As a result, there is a considerable opportunity for conservation agencies to engage in "Nature Markets" and receive compensation for stewardship of the land contracted under the BNG agreement (Webster et al., 2023). Uncertainty remains, however, around the end-result for biodiversity in reality and overburdening of regulatory responsibilities on a limited resource of the local planning authorities and their ecological advisers (Davidson, 2020; zu Ermgassen et al., 2021). There is potential here for palaeoecology to contribute to a more practical understanding of temporal ecosystem dynamics over the proposed minimum 30-year period and help to secure sufficient funding for effective restorative management of the site through predictive scenario and decision pathway modelling (Willis et al., 2010; Gillson et al., 2021). Palaeoecological research could play a vital role in establishing improved evidence-based targets and resilience of BNG-realised sites into the future, which one respondent states "*…is really needed to ensure that biodiversity accounting (BNG and EnvGain etc.) are not just badges such as BREEAM* [Building Research Establishment Environmental Assessment Method] *and others before, and* [will] *lead to real ecosystem repair"*. This kind of application is both highly relevant to current environmental policy and is attractive for practitioners.

Whilst there may be some unexplored potential as discussed above, the fact that "Financial constraints" and "Lack of time" are identified as key barriers suggests that palaeoecological research will remain vulnerable to falling off the priority list for conservation practitioners. In order to facilitate the opportunity, it is important that practitioners be provided with better information of the cost

implications, rather than discounting palaeoecology based on pre-conceptions. For example, one respondent described the difficulty of "*justifying long winded research*". Whilst perceptions of palaeoecological investigation as long, expensive, and resource-intensive are not entirely incorrect, there is now a clear impetus to promote the value of this research for conservation (Smol, 1992; Saulnier-Talbot, 2015). There are also options for conducting palaeoecological research in less resource intensive ways, such as the use of Spheroidal Carbonaceous Particles (SCPs) instead of Pb^{210} for dating 19th Century sediments (Rose et al., 1995). Even simpler chronologies can be investigated through top–bottom analyses, which only sample the top and bottom of a sediment core (Dixit et al., 1999). The bottom can be taken to represent a non-specified "past" or can be dated via radiometric dating, although this does invoke additional cost. Whilst this approach has limitations regarding the low resolution of the data, it provides a cost-effective and time-efficient method to conduct palaeoecological research, especially when working across numerous sites. The validity of this approach is demonstrated by its use in informing the EU Water Framework Directive classifications based on palaeolimnological reference conditions for UK lakes (Bennion and Simpson, 2011). Another potential way to reduce cost to the practitioner could be through the use of a specialist consultancy, thereby reducing the need for in-house equipment and expertise for conservation organisations interested in conducting such research. One such consultancy, ENSIS Ltd, ran between 1988 and 2018 as part of UCL's Environmental Change Research Centre. During its lifespan, ENSIS conducted palaeoecological research and produced numerous reports for the Environment Agency and Natural Resources Wales amongst others, exemplifying a novel pathway to access palaeoecological research (Goldsmith et al., 2005; Shilland et al., 2016). This kind of approach could address the concerns respondents raised around a "Lack of expertise", as this can be made available with appropriate support through such outsourcing.

4.3 Communication

A further barrier ranked highly amongst respondents was "poor communication". This is unsurprising given the findings of previous reviews reflecting the gap between ecologists and palaeoecologists, as well as across a very wide range of academic–practitioner knowledge exchange (Clarke and Lynch, 2016). Much of the palaeoecological research is primarily published in academic journals, and this is perpetuated by the academic system which incentivises researchers to publish in the highest impact journals. Access to these journals is often behind paywalls, requiring subscriptions that would in almost all cases be an unjustifiable cost for a conservation organisation. Whilst the simple issue of cost is starting to change with the rise of the "open research" culture in universities and research centres, this does not necessarily make the articles anymore digestible for a non-academic reader. Expectations for an article to meet standard criteria can preclude many articles from being accessible to a wider audience. The extensive use of jargon and unfamiliar language in traditional academic writing does not facilitate good communication with practitioners and is likely to deter the lay reader. For palaeoecology this is doubly so, where the language and terminology will be even further removed from the vernacular of a typical conservation practitioner than, for example, that relating to theoretical ecology. As discussed above, the mixed understanding of palaeoecology among the survey respondents suggests that removal of jargon is an important step in improving communication. One way this could be done is through the improved training of researchers and students in soft skills, such as project management and communication (Dillon et al., 2022). Interestingly however, it should be noted that this was ranked the least desirable of the solutions by survey respondents who tended to value solutions that provide them with direct access to information in a more palatable format, rather than those that maintain reliance on academics to communicate.

A common theme that emerged was a desire for more applied research and access to case studies of palaeoecological work, which would help to express the research in more relevant terms for practitioners. There is a relatively large body of applied research, but clearly the results speak to an issue in the dissemination of this work to practitioners. This is supported by the relatively high ranking of "Unsure of relevance" as a barrier. Much of this literature is within specialist journals, such as the Journal of Palaeolimnology (e.g., Davidson et al., 2018), which conservation practitioners seldom have access to (Jarvis et al., 2020). It is less so found in more generalised ecological or biological journals, which makes it access even more difficult for the average conservation professional (Rull, 2014). On the other hand, there have been increasing efforts to publish applied research in more management-focused journals such as "Lake and Reservoir Management" (Paterson et al., 2020) and "Restoration Ecology" (Walton et al., 2021), although neither of these were mentioned by participants. Arguably, trade publications are a better avenue for dissemination, although this was ranked as middling as a solution. Despite this, many respondents referred to publications such as CIEEM's *In Practice and British Wildlife*, which are intentionally written in more accessible language and have a wider readership amongst UK conservation practitioners. There are only a handful of articles referring to palaeoecology that have been published in either of these publications, reflecting a wider dearth of palaeoecological studies featured in practitioner magazines (Davies et al., 2014). For example, and somewhat uniquely, an article in a recent issue of British Wildlife discusses the use of palaeoecology in agricultural pond restoration (Sayer et al., 2022). In CIEEM's professional news bulletin In Practice, it appears that palaeoecological work is less common and, if present, tends to be found in the section that summarises and reviews new academic work. Our study suggests that, while there is an absence of readily accessible material, there is an appetite among practitioners for such information on the value of palaeoecological approaches. This should provide a strong impetus for palaeoecologists to design and disseminate their work via more accessible publications and mediums.

The other solution involving direct access to information was a strong desire for a centralised database, comparable to existing platforms commonly used by conservation practitioners, such as DEFRA's MAGIC Map (DEFRA, 2023). Many also expressed that access to the data in GIS format would be helpful (described as a

possible "*game changer*"), which would enable them to easily see any data or case studies locally or contextually relevant to their work. As discussed above, there is clearly an issue with the accessibility and dissemination of existing work, so the creation of a centralised resource is a key recommendation from the present research and to the knowledge of the authors, there is no such resource currently in existence and neither is one being developed. This could be modelled on similar platforms such as the Conservation Evidence project referenced by respondents as a valuable case study database, which provides more accessible, synthesised information from studies related to management interventions (Sutherland et al., 2019). In relation to concerns around resources, the existence of such a repository would not only save time for practitioners, but also remove the need for journal subscriptions and expertise needed to interpret articles directly. A key question to address would be where such a database would be hosted and maintained and by whom. It would seem most logical for it to exist on a platform already visited by practitioners, such as MAGIC Map and DataMapsWales. Local options could be further explored, such as Surrey County Council's Interactive Map (Surrey County Council, 2023). This map is hosted on ArcGIS Online, which is a platform also used by many conservation organisations and therefore would easily enable data sharing and exchange. Another key consideration is around the resource implications of initial population and subsequent maintenance of the database. Conservation Evidence receives extensive public sector and private funding and is run by an extensive team of academics (Conservation Evidence, 2023). Creating an equivalent for palaeoecological research could be labour intensive and therefore, costly and would also require co-operation from various authors with possible concerns for their intellectual property. The difficulties of such co-ordination are apparent when reflecting on "Carbydat", a pioneering online database for sharing UK SCP data, which fell into disuse due to the time required to update and maintain it (Swindles, 2010; Rose, pers. comm.). To move forward, a thorough exploration of options is essential for progressing the integration of a palaeoecological toolkit for conservation practitioners via more centralised and accessible information.

Communication also needs to be bilateral to move away from overvaluation of "expert" opinion and the "monologue" style of information transfer from researcher to practitioner (Lee and Garvin, 2003). One medium for this can be at joint workshops and conference events, where there are spaces for direct knowledge exchange between the two groups (Saulnier-Talbot, 2015). There are existing examples of this, such as conferences run by the UK and Ireland Lake Network (UKILN) where palaeoecologists have had a platform to present their research directly to lake managers (Pinder, 2013). Similarly, talks on palaeolimnology have regularly featured in the North American Lake Management Society's annual symposium since the mid-1980s (Paterson et al., 2020). Whilst workshops have clearly proved popular within aquatic conservation, further raising the profile of palaeolimnology, respondents in this study ranked themed conferences and workshops significantly lower than the two solutions discussed above. This may be a result of practical consideration: one respondent stated that "*I like the idea of a professional group or conferences but realistically I, and most of my colleagues, would struggle to find time to attend anything more than a one off*". If these events were to take place, there would need to be consideration on seasonal pressures and resources on conservation practitioners, as well as on which intermediary body would be best placed to organise it (Quinn, 2021). Another interesting point relating to bilateral communication was captured in a comment; "…*some conservation management could adversely impact palaeoecological resources e.g., through lake restoration*". There is indeed a tangible possibility that the scope for palaeoecological work will be compromised if conservation practitioners are not aware of the risk of destruction to potential archives when conducting habitat management. A classic example of this would be dredging, where with proper communication, cores could be collected prior to it taking place or from "saved" areas that have not been dredged. This would provide opportunities to study, for example, the effectiveness of restoration techniques or appropriateness of restoration targets (Alderton et al., 2014; Bennion et al., 2018). There is perhaps also a point here regarding palaeoecologists taking adequate time to better understand typical land management practices in their areas of study so that they may account for the potential impacts these can have on their samples.

Some of the discussion above points to areas for further investigation to better understand the diverging priorities and drivers of conservation actors and how they impact the sectors" ability to engage with palaeoecological research. Such insight would be invaluable to further indicate the most appropriate communication mechanisms for different groups of conservationists.

4.4 Limitations

All online surveys are subject to some inherent limitations, as the researcher inevitably loses control of the distribution and therefore complete knowledge of the population to which the survey was exposed (Menon and Muraleedharan, 2020). Additionally, as the survey was voluntary it is subject to respondents with biased opinions (Andrade, 2020). People with a particular interest in a topic are more likely to complete a survey on it, which again may lead to bias in the sample (Groves et al., 2004). On the other hand, we consider that the advantages of online surveys, including cost-effectiveness, ease of distribution and providing access to new sampling populations, outweigh the limitations for this study (Wright, 2005; Queirós et al., 2017).

With regards to the sample demographic, there was a high environmental NGO response rate in comparison to other sub-sectors. This is a likely result of the cascaded distribution of the survey, as mentioned above, but is nevertheless considered to be a reflection of where a significant concentration of conservation practitioners is employed. Any results, therefore, should be considered in view of this, which is likely to reflect more extreme resource constraints than other sub-sectors. Additionally, there was a higher proportion of non-experienced over experienced practitioners, providing results that are more influenced by those

without prior experience with palaeoecology. This could mean conclusions are less well-informed than might otherwise be the case but is arguably more likely to truly represent the lack of experience in palaeoecology across the sector. Finally, the survey itself and subsequent discussion of results are primarily focused on the UK conservation context, which might reduce in its applicability and relevance outside of the UK. This did, however, enhance the opportunity to provide specific recommendations for integrating conservation and palaeoecology in the UK.

4.5 Recommendations

The results of this study indicate a positive opportunity for palaeoecologists to improve their connections to a receptive conservation practitioner community. Making the most of these opportunities is pertinent to support conservation science and practice in addressing local and global scale biodiversity loss. Several potential directions, summarised in Figure 6, could be taken:

1. The research community should disseminate palaeoecological work through different avenues in order to ensure it reaches conservation practitioners in an accessible format. One key method for this would be the publication of case studies of applied palaeoecology in journals and bulletins commonly read by conservation practitioners. In the UK, these would be publications such as CIEEM's *In Practice* and BW Publishing products *British Wildlife* and its subsidiary *Conservation Land Management*, all of which were mentioned by respondents. This could be achieved as part of the traditional research publication process, with the author also writing a shorter, summary version of their article in simpler format to submit to such publications. Communicating through these routes is important to increase practitioners" exposure to applied palaeoecology and its potential to support conservation work.
2. Outreach by palaeoecologists to conservation organisations would be beneficial to improve communication and mutual understanding of current challenges and drivers in conservation, and how they might be supported. This could include an offer of basic training on applied palaeoecology for practitioners, which could produce project collaboration opportunities. This is a relatively low-cost option for institutions and researchers for advancing their profile and impact, and this study suggests that it would be an effective pathway for progressing communication and integration.
3. The creation of an online GIS-integrated data platform for practitioners to view previous examples of applied work and case studies in a spatial format would be another way to progress the integration of palaeoecology. This could be modelled off existing platforms, with the intention of providing two interfaces for practitioners. The first being a repository with more detailed synthesised findings in plain language, and the second being an overview map with links to these case studies accessible via point data at the study location. This would be most effective integrated into existing mapping platforms at both local and national scale, as these are the scales most practitioners work at. There would, however, need to be serious considerations around resources for funding, hosting, populating, and maintaining this platform.
4. To provide more readily accessible opportunities for practitioners to utilise palaeoecological tools, the re-establishment of palaeoecological consultancy services would provide options for organisations that do not have the time or resources for in-house expertise and equipment. This should be alongside the outreach described above, so that organisations are aware of the value and existence of these consultancy opportunities. Funding could derive from a variety of sources, but collaborative grant applications to factor-in the consultancy would enable more organisations to access the service.

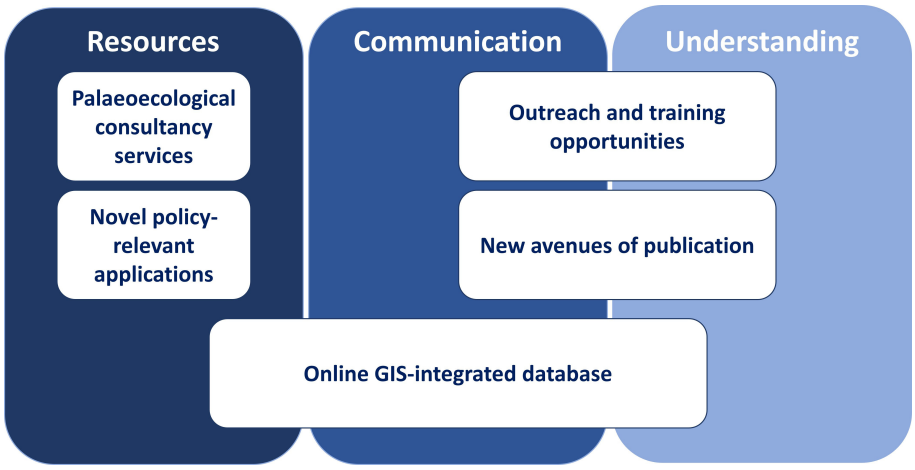

FIGURE 6
Key recommendations for better integration of palaeoecology and conservation practice and the relationship to key themes emerging from the survey.

5. This study has also highlighted numerous opportunities for further research in this area. Of primary importance would be exploratory studies to test the potential for palaeoecology to support important, new and upcoming legislation, given the importance of policy drivers to conservation bodies. One example of which would be testing methodologies to apply palaeoecology to analyse nature finance schemes, such as assessing the feasibility of temporal projections made in Biodiversity Net Gain. This would be ambitious and would need to be contextualised in unprecedented environmental drivers but could build upon existing work looking at ecosystem resilience (e.g., Gillson et al., 2021). Any progress in this area would both enhance the palaeoecological toolkit through exploration of cross-disciplinary and applied opportunities, as well as provide important novel evidential mechanisms serving conservation.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Research Integrity and Governance Office, University of Surrey. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

BS: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Data curation. HB: Supervision, Writing – review & editing. SM: Formal Analysis, Supervision, Writing – review & editing, Methodology. RM: Supervision, Writing – review & editing. MW: Supervision, Writing – review & editing, Methodology.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1304510/full#supplementary-material

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