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USING 3D POLLEN MODELS AND PARTICIPATORY PALAEOECOLOGY TO CONNECT PEOPLE WITH INTANGIBLE PALAEOENVIRONMENTAL RECORDS

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Abstract

Quaternary palaeoecology can provide important insights for navigating Earth's biodiversity and climate crises, but this requires results to be effectively connected with people outside academia. 3D-printed pollen models are a highly effective tool for communicating pollen-related science with diverse audiences, and we suggest that they could also drive new forms of public participation in palaeoecology. 3D models can help people learn aspects of pollen identification; we suggest that they could be used to train citizen scientist 'para-palaeoecologists' who can contribute to the palaeoecological research process. And, by making an otherwise intangible proxy visible and physical, they could facilitate the development of 'ethnopalaeoecology' approaches, in which researchers and communities integrate scientific research and traditional ecological knowledge to generate holistic histories of socioecological systems.

Communicating Quaternary ecology

Quaternary palaeoecology is important on multiple levels: for understanding the nature of past ecosystem dynamics, for helping to make sense of ecological patterns in the present, and for providing a crucial guide to their future. Data derived from sub-fossil pollen (including spores from non-seed plants) plays a significant role in uncovering vegetation histories; palynology has been called 'the single most important branch of terrestrial palaeoecology for the late Pleistocene and Holocene' (Roberts, 2014, p. 33). It can reveal the limits of ecosystems' resilience, alternative baselines for their restoration, and even ecological surprises, like ecosystems and species associations which do not occur today (Williams and Jackson, 2007; Willis et al., 2010; Wilmshurst et al., 2014). As we aim to navigate Earth's twin crises of biodiversity loss and climate change, it is therefore critical to communicate the results of palaeoecological research beyond the scientific community – from resident communities and land managers to regional, national and international policy makers.

There are a number of challenges to effectively communicating research from Quaternary palynology to wider audiences (Davies et al., 2014). These include publications being externally inaccessible and/or restricted to disciplinary siloes, mismatches of priorities between palaeoecologists and potential research users, low familiarity with palaeoecological data, and a lack of time and resources to become acquainted with it (Schafstall et al., 2024; Siggery et al., 2023). Another potentially significant barrier is the nature and presentation of palaeoecological data. Pollen grains are microscopic, so if they are perceived at all, it is usually because they are causing an allergic reaction – a challenging starting point for communicating research! Palynological data generally take the form of pollen and spore taxon counts set against subsample depth and age, whose interpretation – especially when presented in standard stratigraphic graphs – is not intuitive. As a result, palaeoecologists often explore different ways to translate their data into more accessible formats (Seddon et al., 2014). These can range from artistic approaches (González-Arango, 2023) and storytelling (Phillips, 2012) to further analyses which can convert pollen data into land cover maps (Bunting et al., 2018; Bunting and Middleton, 2009).

In this article, we suggest an additional way for palaeoecologists to engage a range of audiences with vegetation histories: giant, accurate 3D models of pollen. These are easy to see, can be touched and held, and open up new dimensions through which people can engage with Quaternary palaeoecology.

3D pollen: a primer

There are several ways to produce 3D pollen models (for an overview, see Wilson, 2023). One of the best and most widespread approaches is using a confocal laser scanning microscope. Similar to a medical CT scan, this builds up layers of tightly focused, high-resolution images through the depth of a pollen grain which can be processed to derive a 3D model of its surface structure. These digital models can then be converted into physical objects using a 3D printer. This process was pioneered by Holt and Savoian (2017) and has since been adopted and adapted by several other groups, resulting in multiple online sources of 3D pollen models (Perry et al., 2017; Stevenson and Kaikkonen, 2019; Wilson, 2023; for links to databases, see 3Dpollenproject.wixsite.com/main).

Visually striking, tactile models of pollen grains have found a multitude of uses in communicating science, including Quaternary research, to public audiences (for more examples, see Wilson, 2023). They have been deployed by botanic gardens and natural history museums to illustrate and explain past environmental change, pollination and plant life cycles in exhibitions and hands-on education sessions (Fig. 1). Scientists have used them in a range of ways with school children – from exploring models in virtual reality to hiding pollen models in sand to simulate the Quaternary palynology research process. With accompanying audio descriptions, models have been included in a 'museum in a box' activity for visually impaired students to explore and discover. And giant pollen models, made in concrete and weighing more than a tonne, have recently been installed in a public art display in Helsinki, Finland (for this example, see Hayes, 2024).

In our experiences, and those of colleagues who have also used them, 3D pollen models are a potent tool for sparking discussions and engaging wider audiences about pollen and related research. Previous pedagogical research has shown that, in addition to being immensely useful for making science more accessible for people with visual impairments (Koone et al., 2022), tactile models also help engage

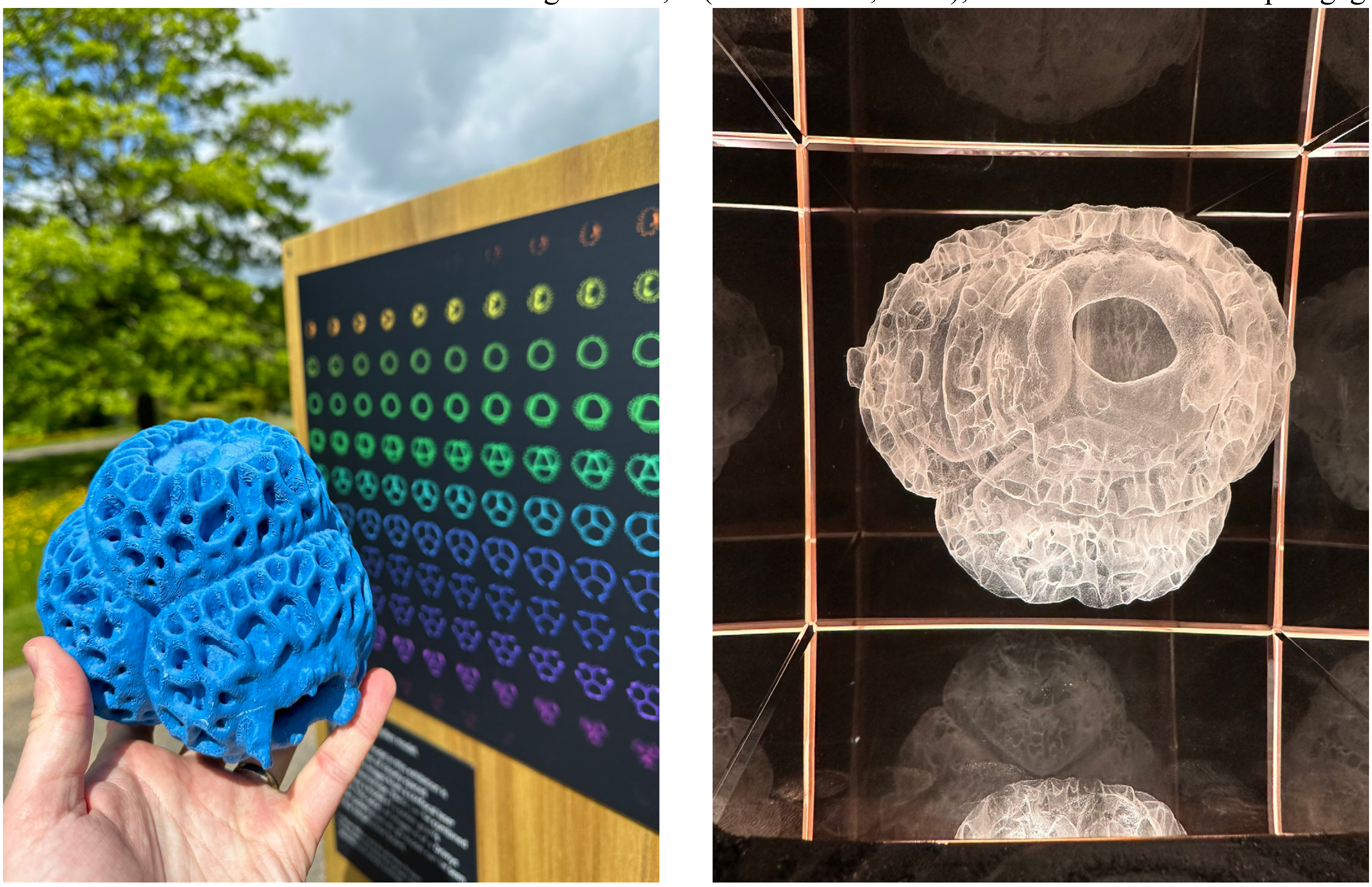

Figure 1: 3D pollen models in science exhibitions. *Left*: a 3D-printed model of *Drimys winteri* (Winteraceae) pollen with an interpretation board showing the scans that produced it, part of the Wonder of Pollen exhibition at RHS Garden Harlow Carr (Harrogate, UK, 2024). *Right:* Drimys pollen model etched into a glass block in the Bees: a Story of Survival exhibition at the World Museum (Liverpool, UK, 2024-25).

audiences across a wide spectrum of prior knowledge (Harris et al., 2022; Ramirez and Gordy, 2020). Compared to standard approaches, physical models can improve and deepen participants' understanding of intangible concepts, especially among more disadvantaged learners (Gordy et al., 2020; Harris et al., 2009; McMillan et al., 2023). As a result, 3D pollen models are a highly useful and effective way to present Quaternary palynology to public audiences – but how else could they be used? We suggest that they could be central to the development of 'participatory palaeoecology', and outline two potentially complementary approaches we are developing through OJW's Knowledge Exchange Fellowship funded by the Natural Environment Research Council. It is our hope that these approaches will come to play an important role in bringing communities into the palaeoecological research process, with numerous potential benefits – particularly around understanding Quaternary ecology.

Para-palaeoecologists

Processing sediment cores into microscope slides then identifying and counting pollen grains is often a painstakingly slow process which places conspicuous limits on the pace of palaeoecological research. One highly technical solution to this problem is developing computational approaches to automate pollen detection and identification (Holt and Bennett, 2014; Martinsen et al., 2024; Olsson et al., 2021). Notably, the confocal microscopy data used to derive 3D pollen surface files can be a useful input into these algorithms (Romero et al., 2020). However, while these systems continue to improve, they have not yet been proven to be suitable for diverse, complex and/or frequently damaged Quaternary pollen assemblages.

An alternative – or complementary – solution might be to explore the potential of citizen science in palaeoecology. Citizen scientists have been tasked to speed up arduous, repetitive and hard-to-automate tasks in other areas of ecological research, such as transcribing label data from digitised herbarium specimens (De Smedt et al., 2024). Analogously, para-taxonomists – community members local to study ecosystems, trained in specimen collection and species identification – can provide important capacity and support for the continuous monitoring of ecosystems (Basset et al., 2004). 3D pollen models can help non-specialists to appreciate key features of pollen morphology, in particular the relationship between 2D light microscope images and grains' 3D reality. Consequently, they could help train citizen scientist 'para-palaeoecologists' to identify and count pollen, especially when used in conjunction with other pollen identification training resources such as eSlide (Hutchinson et al., 2022; see https://www.staff.ncl.ac.uk/stephen.juggins/eSlide/). We plan to explore this prospect further by building on public pollen identification training workshops previously organised at the Humberhead Peatlands National Nature Reserve as part of the Heritage Lottery-funded 'Reconstructing the 'Wildscape'' project (https://projectwildscape.wordpress.com/2019/07/19/palaeofest-citizen-science-with-microscopes/).

Incorporating 'para-palaeoecologists' into palaeoecological research would be a significant departure from standard processes, but it could potentially be highly beneficial. Having to provide initial training to citizen scientists would delay the beginning of pollen counting and slow its early stages, payments for para-palaeoecologists would be an extra cost for projects, and oversight would be required throughout to assist with and verify identifications. However, these drawbacks may well be offset by increasing academic palaeoecologists' capacity – allowing multiple cores to be analysed simultaneously and freeing up researchers to generate grant proposals, undertake higher-level analyses, write up papers and more. Indeed, if it can be successfully deployed, this approach may allow significant parts of palaeoecological investigations to be undertaken semi-independently in non-academic settings, such as by land managers interested in their application to conservation actions and restoration baselines (Siggery et al., 2023). However, researchers will need to be conscious of the power dynamics at play in these circumstances, as relationships between academics and para-palaeoecologists will become exploitative if citizen scientists are viewed simply as a cheap way to outsource important research activities.

Training citizen scientist para-palaeoecologists could open up Quaternary research to new participants by helping them to assume the role of a researcher. But 3D pollen models might also be used to connect communities and palaeoecologists in ways which shift the focus from academics and scientific knowledge to communities themselves.

Ethnopalaeoecology

Knowledge of past ecological change is important for a range of purposes, from interpreting historic human-environment relationships to determining ecosystems' resilience to future disturbances (e.g. Rull, 2021; Willis et al., 2010). It is important that palaeoecological research be accessibly shared with relevant communities so that they can act on the insights its findings can provide. This can be thought of as 'knowledge repatriation' – taking results out of the relatively exclusive, often English-speaking academic environments in which they are generated, published and discussed, and returning them to the communities they concern. As highlighted above, 3D pollen models can be enormously helpful for this. However, they could also help uncover and centre communities' own interpretations of palaeoecological data – with benefits in turn to the scientific community.

Figure 2: using 3D pollen models to discuss palaeoecological methods with Kaingang community members of Terra Indígena Toldo Imbu (Santa Catarina state, Brazil).

Richer and Gearey (2017) demonstrate that there are multiple valid ways to interpret data on Quaternary vegetation change. As well as being viewed through a standard ecological 'lens', it is possible for palynological data to be interpreted through a paradigm of traditional ecological knowledge (TEK). For example, whereas standard palaeoecological interpretations might focus on signals of ecosystem 'degradation' with increasing human impact, an interpretation centring TEK might describe the same signals as demonstrating the landscape's increasing potential to support the wellbeing of its inhabitants (Richer and Gearey, 2017). These alternatives do not inherently conflict with one another; rather, they are complementary, each building on long-established ways of understanding the interconnectedness of the natural world. By analogy with disciplines such as ethnobotany and ethnoecology (respectively the study of cultural perceptions of, and relations with, plants and ecosystems), this merging of TEK and traditional palaeoecology could be termed 'ethnopalaeoecology'. Making space for TEK in our interpretations of fossil pollen records can help us to acknowledge the connections of plants to human cultures and develop more holistic ways of understanding past environmental change (Richer and Gearey, 2017). Practically, in concert with other tools such as pollen-derived land cover maps (Bunting et al., 2018), 3D pollen models could play a useful role in facilitating the bi-directional knowledge exchanges that ethnopalaeoecological approaches would require. By making intangible fossil pollen records visible and tactile, and by interactively illustrating how Quaternary palynology works, they could help open up community conversations about the research process and how the ensuing results are used. These could focus on questions such as how well culturally important plants are represented in the fossil pollen record, and potentially generate enriched descriptions of and explanations for socio-ecological changes detected in proxy records. In doing so, they would build on knowledge repatriation towards a more equitable form of knowledge co-creation – another new frontier for palaeoecology.

Through OJW's Knowledge Exchange project, we are working towards developing ethnopalaeoecological approaches to build a holistic history of southern Brazil's Araucaria forests – an ecosystem which was significantly shaped by Indigenous people over recent millennia (Robinson et al., 2018; Wilson, 2022). The initial stages took place in 2024. Working with colleagues from Universidade Comunitária da Região de Chapecó who deliver intercultural teacher training on Indigenous territories, OJW visited three Kaingang communities in order to introduce himself and the proposed project and seek support for further collaboration (Fig. 2). Following positive responses from community members, knowledge repatriation workshops will be held in 2025, sharing insights from recent palaeoecological and archaeological research (e.g. Corteletti et al., 2015; de Souza, 2018; Wilson, 2022), and we are currently applying for funding to extend this to collaborative ethnopalaeoecological research over the coming years.

Conclusion

There are many good reasons not to keep palaeoecological research sequestered within the scientific community. 3D pollen models have demonstrated their considerable worth for explaining, illustrating and translating palaeoecological research for non-expert audiences, and they have significant potential for bringing communities into the research process too – from training para-palaeoecologists to facilitating conversations around novel TEK-informed interpretations of data. As available datasets of 3D pollen files continue to grow and become increasingly representative of the global flora, these approaches will become more feasible and accessible. And the potential of these approaches is not solely confined to pollen and spores, either – 3D data is becoming available from a range of other microfossils, including foraminifera and phytoliths (for examples, see https://3dpollenproject.wixsite.com/main/3d-not-pollen). The increasing availability of these 3D microfossil models promises to continue to revolutionise the ways in which public audiences can engage with – and participate in – the processes and outputs of palaeoecological research.

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