More than dirt: sedimentary ancient DNA and Indigenous Australia

Dawn Lewis[1], Rebecca Simpson[2], Azure Hermes[3], Alex Brown[2], and Bastien Llamas[1]

[1]The University of Adelaide
[2]Telethon Kids Institute
[3]Australian National University National Centre for Indigenous Genomics

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Abstract

The rise of sedimentary ancient DNA (sedaDNA) studies has opened up new possibilities for studying pre-historic ecology. The use of sediments to identify organisms even where macroscopic remains are limited or no longer exist is an exciting and potentially ground-breaking area of genomics. There are special considerations however when managing this substrate in Indigenous Australian contexts. Sediments and soils are often considered as waste by-products during archaeological and paleontological excavations, and as such are not typically considered of high value in ethical considerations in traditional western research. Nevertheless, the product of sedaDNA work – genetic information from past fauna, flora, microbial communities, and human ancestors – is likely to be of cultural value for Indigenous peoples. We argue that the integration of Traditional Knowledges into sedaDNA research would a) allow identification of sensitive, secret, or sacred genomic data, and b) improve research outcomes by providing ecological context for species through multi-millennia oral histories.

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Authors

Ms Dawn Alison Lewis

Ms Rebecca Simpson

Mrs Azure Hermes

Professor Alex Brown

Associate Professor Bastien Llamas

Dawn A Lewis[1,2,#], Rebecca Simpson[3,4], Azure Hermes[3], Alex Brown[3,4], Bastien Llamas[1,2,3,4]

[1] Australian Centre for Ancient DNA, School of Biological Sciences and Environment Institute, University of Adelaide, SA 5005, Australia

[2] ARC Centre of Excellence for Australian Biodiversity and Heritage, University of Adelaide, Adelaide, SA 5005, Australia

[3] National Centre for Indigenous Genomics, Australian National University, Canberra, ACT 2601, Australia

[4] Black Ochre Data Labs, Telethon Kids Institute, Adelaide, SA 5000, Australia

[#] Corresponding author: dawn.lewis@adelaide.edu.au

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Abstract

The rise of sedimentary ancient DNA (sedaDNA) studies has opened up new possibilities for studying prehistoric ecology. The use of sediments to identify organisms even where macroscopic remains are limited or no longer exist is an exciting and potentially ground-breaking area of genomics. There are special considerations however when managing this substrate in Indigenous Australian contexts. Sediments and soils are often considered as waste by-products during archaeological and paleontological excavations, and as such are not typically considered of high value in ethical considerations in traditional western research. Nevertheless, the product of sedaDNA work – genetic information from past fauna, flora, microbial communities, and human ancestors – is likely to be of cultural value for Indigenous peoples. We argue that the integration of Traditional Knowledges into sedaDNA research would a) allow identification of sensitive, secret, or sacred genomic data, and b) improve research outcomes by providing ecological context for species through multi-millennia oral histories.

Keywords

TEK; ancient DNA; Indigenous; Aboriginal;

Benefit sharing / positionality statement

This article is an opinion piece designed to communicate the responsibilities of ecological researchers in Australia as that research pertains to the emerging field of sedimentary ancient DNA and Indigenous communities. As such, there is no new data to provide or site. The authors identify in the following ways. DL is a Woolwonga woman, AB is a Wadi Wadi and Yuin Nation man, and BL is a non-Indigenous man, and they are visitors to the Kaurna Land on which they live and work; RS is a Kaurna/Narungga woman from South Australia and Indigenous Fijian from SavuSavu, Fiji Islands, currently living and working on her Kaurna homelands; AH is a Walubara Yidinji woman, from Cairns, Far North Queensland who is a visitor to the Ngunnawal Land on which she lives and works. All authors endeavour to walk on these respective Country with care. This work aims to highlight the importance of researcher collaboration with the diverse Indigenous identities in modern day Australia. The authors hold no authority to represent all Indigenous peoples across Australia and thank those who entrust their knowledge to their care.

Introduction

Modern day Indigenous Australia is comprised of two distinct cultures: Aboriginal and Torres Strait Islander. Each culture is comprised of hundreds of distinct Nations or Tribes that in practice should be considered as discrete entities with their own laws, lore and relationships with non-Indigenous Australia. Aboriginal and Torres Strait Islander peoples (hereafter respectfully referred to as Indigenous peoples) have been connected with ancestral lands, seas and waterways since time immemorial according to oral traditions, to the point where the term "Country" defines the place, the biota and microbiota, as well as peoples' culture, language, spirituality, identity, familial and social bonds, and stories. As a western echo to Traditional Knowledge, archaeological evidence suggests Australia has been occupied by humans for at least fifty millennia (Clarkson et al., 2017; Dortch & Malaspinas, 2017; O'Connor, Louys, Kealy, & Samper Carro, 2017). The continuing transgenerational and strong cultural relationship with Country links the ecological health of the Australian landscape with human occupation from at least midway through the late Pleistocene, and continues to evolve with the introduction of non-native biota (Fletcher, Hall, & Alexandra, 2021; Trauernicht, Murphy, Tangalin, & Bowman, 2013; Turner & McDonald, 2010, pp. 117, 176-188). Ancient DNA studies reach into these time periods and can be used to enlighten local and regional ecological history (Alter, Newsome, & Palumbi, 2012; Hofman, Rick, Fleischer, & Maldonado, 2015).

Sedimentary ancient DNA

Sedimentary ancient DNA (sedaDNA) can be found both intracellularly in small pieces of tissue, and extracellularly, particularly adsorbed with negatively charged minerals and biomolecules (Massilani et al., 2022; Pedersen et al., 2015; Pedreira-Segade et al., 2018; Wnuk et al., 2020). Allophane from volcanic soils and montmorillonite clay mineral have a high affinity to nucleic acids (Huang et al., 2014) and while these molecular interactions can protect the DNA molecules over time (Blum, Lorenz, & Wackernagel, 1997), they may also impede the DNA extraction and in vitro amplification processes (Pedersen et al., 2015; Wnuk et al., 2020). For example, humic acids are known inhibitors of enzymes used to amplify DNA in vitro—using a standard molecular biology method called PCR, or polymerase chain reaction (Simmons & Cross, 2013, p. 276). The humic acids and metal ions commonly found in soils and sands have similar characteristics to DNA molecules and as such bind nucleotides and inhibit DNA isolation (Pedersen et al., 2015; Wnuk et al., 2020). Horizon-stabilising techniques have indicated that sediment samples impregnated with resin can yield high DNA content and limit these inhibiting factors, resulting in better DNA sequencing library preparation efficiency than when analysing loose sediments (Massilani et al., 2022).

Using sedaDNA in ecological studies

The use of sedaDNA in ecological studies is currently limited, but it is emerging as a powerful methodological framework as specialised statistical analyses are being developed (Chen & Ficetola, 2020). Techniques for the extraction, isolation and downstream analysis of ancient DNA are now so advanced that ancient sediments can be used as a genetic substrate to complement, or replace, traditional sub-fossil taxonomic identification (Pansu et al., 2015; Pérez, Liu, Hengst, & Weyrich, 2022; Slon et al., 2017; Thomas et al., 2022). Recovered sedaDNA has come from across the tree of life, including microbes, plants, and animals (Chen & Ficetola, 2020; Pansu et al., 2015; Pérez et al., 2022; Slon et al., 2017; Thomas et al., 2022; Willerslev et al., 2003).

The prospect of extracting genetic material from sediments with stable strata would allow a high-resolution temporal view of the landscape and offer new insights into ecological variation. Recent evidence from Denisova cave suggests that millimetre-scale sediment horizons can be locally stabilised over time (Massilani et al., 2022). The translocation of sedimentary strata, however, whether by climatic or biotic forces, will likely remain the primary confounding factor in sedaDNA studies (Pedersen et al., 2015). Natural variation in geology and biotic factors will mean the severity of stratum translocation will likely vary within and between sites. To address this, Massilani et al. (2022) assert that their technique of impregnating sediment samples with resin not only reduces post-sampling translocation but also allows for clearer assessment of post-depositional movement.

Viable sedaDNA was initially recovered in areas of permafrost when researchers at the University of Copenhagen successfully extracted DNA from sedimentary (dry silty) cores in Aotearoa New Zealand (Willerslev et al., 2003). They also extracted extinct moa DNA from the sand in direct contact with a moa bone. Mitochondrial DNA has been successfully recovered from a variety of species across the mid to late Pleistocene (Slon et al., 2017). Denisova cave has yielded hominin mtDNA between ~100ka to ~200ka (Slon et al., 2017; Vernot et al., 2021). More recently, shotgun sequencing of 25ka-old European sediments allowed the retrieval of genome-wide sequences from humans, wolves and bison, offering insights into the recent evolution of all three species (Gelabert et al., 2021).

Using sedaDNA to assess the impact of cultural ecological management

Anthropogenic transformation can lead to significant changes to a landscape (Garcés-Pastor et al., 2021), and sedaDNA may assist in assessing these effects through time to inform contemporary ecological management plans. Environmental conditions and drivers can be revealed through microbial (Pérez et al., 2022), fungal (Talas, Stivrins, Veski, Tedersoo, & Kisand, 2021) and plant (Edwards et al., 2021; Hudson et al., 2022) sedaDNA. This would be of great benefit in areas where Traditional Knowledges are drawing the attention of non-Indigenous stakeholders, such as the fire-based ecology in Australia. Ecological management practices that utilise fire are integrated in many cultures around the world, including Aboriginal Australians (Coughland & Petty, 2012). Also referred to as cultural burning, the fire-based ecological practices of Aboriginal peoples go as far back as the early Holocene (Matthew A Adeleye, Haberle, Connor, Stevenson, & Bowman, 2021) and have had clear ecological impacts on animal and plant populations (Matthew Adesanya Adeleye, Haberle, Ondei, & Bowman, 2022; Bowman, 1998). Associating ecological communities identified by sedaDNA in stratigraphic horizons with the concentration of charcoal in the sediment can elucidate the effects of fire on the local environment.

Landscapes subject to cultural burnings have greater habitat diversity than comparable regions (Bliege Bird, Bird, Codding, Parker, & Jones, 2008), and the cumulative effects of fire practice over generations lead to the maintenance of high biodiversity (Bliege Bird et al., 2008). The anthropological justifications for this ecological manipulation by cultural burning vary by social and geographic necessity (Gott, 2005; Hill, Griggs, & Bamanga Bubu Ngadimunku, 2000; Yibarbuk et al., 2001). The cultural entwining of fire practices cannot be disentangled from socio-cultural practices (Yibarbuk et al., 2001). The following represent examples of diversity in the practical applications of cultural burnings and are not an exhaustive or exclusive list for the different Indigenous peoples mentioned. Peoples of the Ngaanyatjarra language group in the Western Desert of Australia have associated a decline in desert mammals, specifically the *mitika*(*Bettongia leseur* or rat-kangaroo) with a cessation in cultural burning (Burrows & Christensen, 1990). In south east Australia, annual burnings kept scrublands open for seed germination and movement across Country and in the north maintained diversity of food sources from both plants and animals on Yolngu Country (Gott, 2005; Yibarbuk et al., 2001). The Kuku-Yulanji people of Tropical North East Australia manage the interface of tropical rainforest and open grass-and-bush lands, and each environment's unique resources, through cultural burning (Hill et al., 2000). Some Australian seeds have an obligate fire response to germinate and the increase of vegetative diversity is beneficial to humans and other animals (Bell, Plummer, & Taylor, 1993; Gott, 2005). Identifying changes in sedaDNA communities associated with changes in charcoal concentration would allow identification of wildfires both natural and anthropogenic, where a plateau in species diversity associated with higher charcoal concentration could indicate the presence of cultural burnings. Further, and with relevance to contemporary ecology, cultural burning can control wildfire spread (Coughlan & Petty, 2012; Mariani et al., 2022). It is reported that Traditional Knowledges of fire practices have adapted in many cases to manage the landscape formed by European colonisation (Matthew Adesanya Adeleye, Connor, Haberle, Herbert, & Brown, 2021; Coughlan & Petty, 2012; Hill et al., 2000; Yibarbuk et al., 2001). Collectively, Traditional Knowledges that mediate cultural burning are clearly important in understanding Australian ecology now and in the past and connecting Traditional Knowledges with sedaDNA has the potential to inform ecological management practices.

Traditional Knowledges as sources of information

Researchers have benefited greatly from bridging Traditional Knowledges and the predominant Western systems of knowledge keeping. For example, Noongar (western Australia), Wiradjuri (eastern Australia), Yolngu (northern Australia) Warlpiri (central Australia) and many more Nations, have been specifically acknowledged by modern astrophysicists as keepers of navigational and calendar systems, as well as notable astrophysical phenomena of cyclical and individual incidence (Forster, 2021; Norris, 2016).

Indigenous genetic knowledge has been demonstrated in Indigenous marriage systems. Briefly, traditional marriage is often determined by the moiety to which a person belongs (Turner & McDonald, 2010, p. 23). These moieties have their own names in their Nation's language, but may be referred to in English as "skin groups" in some regions; these moieties have strong connectedness with Country for which members of that group are responsible (Turner & McDonald, 2010, pp. 25, 28, 30). Gamilaraay academic Dr. Jarrod Field demonstrated mathematically the genetic benefits of the Gamilaraay traditional marriage system (Field, 2021). Such systems, which differ between Aboriginal Nations, prevent "wrong-way" marriages (Turner & McDonald, 2010, pp. 25, 29), resulting in lower than expected relatedness in contemporary populations of such small size that western tradition would assume the opposite (McWhirter et al., 2014).

Through the demonstrated anthropocentric Knowledge and given the close relationship of Indigenous peoples in Australia to Country, it is understood that Traditional Knowledges carry in-depth scientific understanding for the complexity of the environment. In cases where the oral history of an area can be shared, Traditional

Knowledges can accurately indicate changes in weather or resources use, or add to our understanding of inter-species interactions, particularly for species that are poorly studied. In the context of determining the drivers and/or impact of ecological change, there is no doubt that sedaDNA studies would benefit from the inter-connectedness with millennia of oral history and Traditional Knowledges.

Receiving Traditional Knowledges is a gift, not a right

It is important for researchers to manage their expectations regarding receiving Traditional Knowledges as Indigenous peoples in Australia continue to recover from intergenerational traumas stemming from historic, and often continuing, colonial practices. Academic Australia has a largely British, or otherwise Euro-centric, history that includes the reverence of humans above all else. Although Indigenous Australians greatly revere the remains of Old People (ancestors), Indigenous genomics in Australia encompasses the entirety of Aboriginal and Torres Strait Islander connectedness to land, flora, and fauna. Akarre Elder Margaret *Kemarre* Turner (Order of the Medal of Australia) demonstrates this as “The Land *is* us, and we are the Land.” (Turner & McDonald, 2010, p. 15). The relationships between Land and Indigenous peoples are not abstract, they are tangible and meaningful.

Indigenous Australians have rules surrounding their Country’s biota, dictated through lore and stories, which often relate to the breeding and hunting seasons as well as other aspects of care for totem animals (Raven, Robinson, & Hunter, 2021; Robinson & Raven, 2020; Steffensen, 2020, p. 95). Indeed, an emu is as much an ancestor as Old People are, though the strength of this connectedness may depend on an individual’s familial lines (Raven et al., 2021). Aunty Margaret *Kemmare*teaches that Aboriginal lore requires plants be respected for stories, food and medicine and that some trees are considered to have become human (Turner & McDonald, 2010, pp. 156-161). These kinship ties integrate obligations to care for Country in perpetuity, in the past, present, and future, and the meaning of which varies with each Nation as they do with the landscape (Raven et al., 2021; Robinson & Raven, 2020). SedaDNA could be utilised by Indigenous peoples to connect oral histories with modern science. Much Traditional Knowledge however, has been repressed and consequently, the continued research on Indigenous peoples, plants and animals is likely to perpetuate harmful colonial narratives, regardless of researchers’ intent (Z. Roberts, 2022). Balancing the potential for sedaDNA research with the risk to harm Indigenous peoples can only be done with direct input and control from Traditional Owners.

Considering the responsibilities of Indigenous peoples in caring for Country is important for researchers that undertake genomic analyses in Australia, where they reasonably encounter all aspects of Indigenous genomics. Like the people who inhabit the continent, the Australian landscape is diverse, from red desert to snowy mountains and even the “oldest surviving rainforest in the world” (P. Roberts et al., 2021). Consequently, land management by Indigenous peoples differs between Nations along with specialised ways of knowing, learning and being (Raven et al., 2021). The interconnectedness of Indigenous peoples and the land they have responsibility for has developed over thousands of generations and the health of the land is so entwined with the health of the people that one cannot be separated from the other (Raven et al., 2021; Robinson & Raven, 2020; Turner & McDonald, 2010, pp. 114, 115). Therefore, when considering Indigenous sedaDNA work, due respect is owed to the biota from across the tree of life that leave their DNA traces in the sediment. As a direct practical consequence, it is paramount to balance CARE and FAIR principles (Carroll, Herczog, Hudson, Russell, & Stall, 2021) when disseminating sedaDNA data.

In such an area, where efforts are made to understand Traditional Knowledges, non-Indigenous researchers may become frustrated at the hesitancy of Indigenous peoples to share their stories, particularly as they relate to ecological, or otherwise non-human entities. But remembering that sediments should be treated with full recognition of their Indigeneity, respecting the sovereignty of Traditional Owners in decision making means they have the right to retain or otherwise mediate the dispersal of that Knowledge (potentially applying Bio-Cultural and Traditional Knowledge label systems (Mc Cartney et al., 2022). Research that engages with, but does not dominate or claim ownership of, Traditional Knowledges will not only improve the ethical standing of the researcher but improve research outcomes through a more holistic understanding of species history.

Conclusion

Indigenous genomics, in particular the study of sedaDNA, is a powerful tool that has the potential to provide Indigenous Nations of Australia with links to their kin and improve ecological research. Respectfully improving the relationship of academic institutions and researchers with Indigenous peoples will be difficult, however, as the historic forced suppression of Traditional Knowledges and Traditional Knowledge systems, in conjunction with the abduction and embezzlement of Indigenous artefacts (including kin/totem flora and fauna), has created intergenerational mistrust of academic activities. The result is a current gap of Indigenous inclusion in rapidly developing areas of genomic science such as sedaDNA. Given the breadth of genomic information from Country available through sedaDNA analysis, engaging Indigenous peoples is key to ensure each Nation is in control of their own narrative.

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Author contributions

DL conceptualised and wrote the initial paper; BL, AB, AH and RS contributed to the writing of the paper.