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Quaternary AUSTRALASIA

SPECIAL ISSUE

ARC Centre of Excellence for Australian Biodiversity and Heritage

AQUA LIFE MEMBERS

Current life members are Jim Bowler, Eric Colhoun, John Chappell (dec), Peter Kershaw, John Magee, Matt McGlone, Geoff Hope (dec) and Jeannette Hope.

Jim Bowler
(Photo credit: socialpolicyconnections.com.au)

Eric Colhoun
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John Chappell (dec)
(Photo credit: Helen Chappell)

Peter Kershaw
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John Magee
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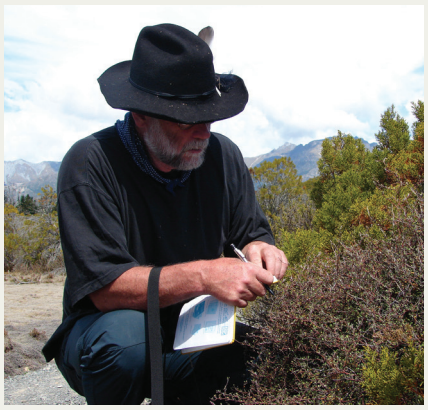

Matt McGlone
(Photo credit: Manaaki Whenua Landcare Research)

Geoff Hope (dec)
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Coring setup at Kandimalal-Wolfe Creek Crater – see Field report: JCU, CABAH and records of environmental change in the north in Special Issue: ARC Centre of Excellence for Australian Biodiversity and Heritage (CABAH). (Photo credit: Michael Bird).

Below:

Halophyte and mallee scrub ring the gypseous shoreline of Lake Chinocup on Noongar Boodja (Country) in southwest Western Australia – see Lunettes and their history: Landscape and climate change in Western Victoria in News from the Field. (Photo credit: Victoria Schwarz).

EDITORIAL

Dear Quaternarists,

Welcome to another issue of *Quaternary Australasia* – this is a big one!

For this special issue, we have partnered with the ARC Centre of Excellence for Australian Biodiversity and Heritage (CABAH) to share highlights from CABAH's seven-year tenure. Many of us in the Australasian Quaternary community have been involved in CABAH to varying degrees, and this issue is a chance for all of us to look back on CABAH's achievements now that the Centre of Excellence is coming to an end. Special thanks go to Dr Haidee Cadd, who served as Guest Editor for the CABAH contributions to this special issue.

This issue also features updates from western Victoria and Lake Mungo in News from the Field. Our Reports section gives a look at four years of the AQUA mentoring program, a workshop for INQUA's "Warm Intervals in the Southern Hemisphere" (WiSH) group, dune development on Flinders Island, and recent meetings at Lake Mungo and Mildura reflecting on cultural and scientific meanings of Mungo.

After five years on the QA editorial team, this will also be my final issue as an editor. Thank you to my co-editors, members of the AQUA Executive Committee over those years, and everyone who submitted their work to QA – it's been a privilege.

Happy reading,

Emma Rehn
Retiring Editor

Lauren Linnenlucke
Editor

Kathryn Fitzsimmons
Shadow Editor

Haidee Cadd
CABAH Special Issue Guest Editor

INTRODUCING OUR NEW SHADOW EDITOR: A/PROF KAT FITZSIMMONS

Kat is a drylands buff; since completing her PhD on the history of aridity in Australia's red heart (ANU, 2007), she has worked on the Quaternary history of dunes, loess, lunettes and ephemeral lakes, as well as human-environmental interactions – in Australia, Central Asia, subhumid Europe, southern and northern Africa.

Her favourite tools are luminescence dating and sedimentology, with a healthy dose of fieldwork. She recently returned to Australia at the end of 2024 to take up an Associate Professorship at Monash Uni after 15 years in Germany, where she was a postdoc and then Group Leader at two Max Planck Institutes, and lately, Professor of Terrestrial Sedimentology at the University of Tübingen. She was also previously Editor of QA from 2007 to 2015 and thought it might be fun to become active within AQUA again!

We encourage authors to use dual place names where possible (e.g., Kati Thanda-Lake Eyre), to acknowledge Country where the work was undertaken, and to acknowledge any Traditional Owner groups involved in the work.

AQUA acknowledges the Traditional Owners of the lands and seas of Australasia on which we live, work and conduct research, and we pay our respects to Elders past and present.

PRESIDENT'S PEN

Dear AQUA colleagues,

It is that time of the year when AQUA holds its Annual General Meeting. I'd like to thank departing members of the committee for their contributions. It was a busy year, and we had a very successful biennial meeting at Minjerribah. I'd like to repeat my thanks to Helen Bostock and the organising committee and to the members of the Executive that contributed to its success. Plans are underway for AQUA 2026 in Sydney during winter. There will need to be some juggling with timing to fit in with other meetings. More soon!

During the year, we submitted a letter to the University of Wollongong appealing for our members to be spared during their 2024 round of cuts. Over many years, and with considerable effort and funding, the University of Wollongong had built one of the nation's leading teams of earth scientists, environmental scientists and archaeologists. The Physical Geography major had already been disestablished and senior management contemplated further reductions. Our letter highlighted the staff's contributions and highlighted that the last few years have seen deep and concerning cuts to Geography and Earth Sciences programs in both Australia and New Zealand, particularly in the Sydney region at Macquarie University and Newcastle University, and Australian National University. New Zealand-Aotearoa's University of Waikato Te Herenga Waka, Victoria University of Wellington and GNS Science have not been spared either. We stressed that by cutting these disciplines, the University of Wollongong will lose its critical edge in these fields, and its leading place in the community. And, of course, our valuable colleagues.

In their form letter reply, the Vice Chancellor explained that the university had seen a decrease in revenue of $35 million in 2024 and that they had identified areas of "unviable teaching activity" and could "no longer justify maintaining our current levels of staffing in some areas". We subsequently learned that seven members accepted voluntary redundancy, mostly in the earth sciences, including a prominent Quaternary scientist, but that there were no forced redundancies. The remaining members are safe from the latest rounds of cuts in 2025. The disciplines survive in reduced form (Archaeology within Forensic Science).

A remarkable dysfunctional gap between private industry and the universities has opened up. Of Australia's 2023-2024 exports, an astonishing ~$388 billion worth or ~59%, relates to the earth sciences, which doesn't only include exploration and resource definition, but environmental and archaeological surveys, ongoing monitoring and remediation. For whatever reason, students are not keen to enter these fields of study, despite attractive salaries. New academic jobs in these fields are practically non-existent. It is puzzling that we are cutting the important science that underpins some of the critical issues of our time such as climate change and resource security.

We have started off 2025 with a healthy (financial) membership of 80. Although our revenue is small, our operating costs are also small. If you are a lapsed member, I encourage you to re-join. The income we receive is vital for keeping the organisation and our somewhat dwindled community viable.

Professor Tim Barrows
AQUA President

THE LEANNE ARMAND TRAVEL AWARD

This award was set up in honour of the Late Professor Leanne Armand (February 1968-January 2022). Leanne was Director of the Australian and New Zealand Consortium (ANZIC) and was also Professor of Micropalaeontology at The Australian National University (ANU). Leanne was a world leader on marine diatoms which she successfully used to reconstruct the waxing and waning of sea ice in the Southern Ocean. She was passionate about training the next generation of scientists and was an advocate for diversity and inclusion.

Funds were donated towards the Leanne Armand Travel Award by family members, colleagues, and friends to help train the next generation of microfossil experts. The award is for postgraduate and early to mid-career researchers based in Australia and is administered by the Australasian Quaternary Association (AQUA).

The award consists of a travel stipend to a maximum of A$3000 and is offered at most once a year to a single candidate. Preference will be given to travel where the applicant is seeking to learn microfossil identification or advanced characterisation techniques from an expert(s). Upon completion of the award, the applicant is to submit a report to be published in *Quaternary Australasia*.

Applications for 2026 will be due in late September 2025 – see: aqua.org.au/sample-page/the-leanne-armand-travel-award for more information on how to apply.

SPECIAL ISSUE: ARC CENTRE OF EXCELLENCE FOR AUSTRALIAN BIODIVERSITY AND HERITAGE (CABAH)

INTRODUCTION FROM THE CABAH DIRECTOR

Associate Professor Tim Cohen

Director, CABAH

Since its establishment in 2017, the Australian Research Council Centre of Excellence for Australian Biodiversity and Heritage (CABAH) has forged new paths in interdisciplinary research, training, and public engagement. Under the leadership of Distinguished Professor Richard 'Bert' Roberts and headquartered at the University of Wollongong, CABAH has brought together researchers, institutions, and First Nations communities to tell a culturally inclusive, globally significant story of Australia's people and its environment. I am honoured to now serve as CABAH Director and welcome you to this special edition of *QA*.

Over the past eight years, CABAH has contributed to landmark discoveries, delivered more than 900 research publications, and deepened our understanding of Quaternary environments through collaborative research across Australia and its northern neighbours. From uncovering early Aboriginal pottery in northeast Australia to documenting more than 500 generations of cultural practice in East Gippsland, CABAH's research has reframed key narratives in archaeology, palaeoecology, genomics, and Earth sciences.

Our commitment to research capacity building is evident in the success of our Research Training and Ethics (RT&E) program, which supported over 50 PhD students and more than 60 postdoctoral researchers. These emerging scholars have been equipped with ethical and professional training prioritising cultural awareness and community collaboration.

Through our Education and Engagement (E&E) program, CABAH reached hundreds of thousands of people. Cross-cultural initiatives, such as the CABAH Art Series and the feature-length planetarium film *The Earth Above,* brought deep-time narratives to life in powerful and accessible ways.

CABAH's contributions to the Australasian Quaternary research community are wide-ranging, having directly supported the next generation of Australasian Quaternary scientists, fostered enduring interdisciplinary partnerships, helped reshape research practices to prioritise inclusivity, and spurred public curiosity and understanding.

On behalf of the CABAH community, I thank Bert for his exemplary leadership and all those who have contributed to this extraordinary journey. I look forward to seeing what CABAH alumni go on to achieve in their careers—particularly those now contributing to the new Centre of Excellence for Indigenous and Environmental Histories and Futures.

With CABAH wrapping up in 2025, this edition celebrates and shares CABAH's achievements to help ensure its resources, outputs, and legacies continue to support the advancement of the Australasian Quaternary research community. This issue of *QA* includes articles, field reports, and stories celebrating the breadth of CABAH's activities, from podcasts to pollen traps to artworks to large-scale databases, and everything in between.

The CABAH team recognises that all our activities take place on Indigenous land. Australia is an exceptional country with a unique cultural heritage and biodiversity that has been under the care of Indigenous Australians for millennia. CABAH is thankful to all communities that have partnered with us in our research.

Figure 1: CABAH Director Tim Cohen (Photo credit: Mark Newsham).

FIELD REPORT: JCU, CABAH AND RECORDS OF ENVIRONMENTAL CHANGE IN THE NORTH

Michael Bird[1] and Cassandra Rowe[1]

1 ARC Centre of Excellence for Australian Biodiversity and Heritage, James Cook University, Cairns, Australia

For many years, lacustrine records of environmental change in northern Australia tended to be focused on the Atherton Tablelands, following the seminal work of Peter Kershaw, and around the coastal fringe. Not surprising, because the strongly seasonal nature of rainfall in the monsoon north meant that many 'lakes' disappeared in the dry season, and the record they contain was therefore degraded. In 2012, the Australian Research Council funded a one-year project to just 'have a look' at a bunch of sites in the Top End to try and locate sites in the savanna that would contain quality records of environmental change that extended to the time of first human arrival; many thanks to whoever reviewed the application! This led to a successful Laureate Fellowship application to develop the most prospective sites. In turn, in 2017, this work was taken up by CABAH. The broader program aimed at understanding environmental change over the last glacial-interglacial cycle around Australia, with the JCU Quaternary crowd contributing to the Top End Flagship.

It is not easy to core lakes in remote northern Australia. Access is often away from roads, and coring must contend with sometimes hard sediments as well as, on occasion, crocodiles. An early raft design that fitted into a golf bag (Figure 1a) was not equal to the task. Using the engineering aphorism 'if it doesn't work, get a bigger hammer', five raft iterations resulted in a hydraulic soil corer mounted on a raft (Figure 1b) that could be dismantled and packed down to fit on an off-road trailer the same width as a Hilux (Figure 1c) that could (therefore) go anywhere a Hilux could go. Sometimes it was easier just to back the vehicle into the lake (Figure 1d). The components were individually light enough to be airlifted by an R22 helicopter into Kandimalal-Wolfe Creek Crater in 2023 to obtain a 15 m core that covers the last 70 ka (Figure 1e).

Extracting decent cores is one thing, but the development of new environmental records in poorly studied regions requires the development of new analytical techniques (Wurster et al., 2015; Haig et al., 2020; Munksgaard et al., 2020). It also requires an interpretive framework for the proxies to be developed, based on results from modern sediments in relation to local environmental conditions (Saiz et al., 2018; Bird et al, 2019; Rehn et al., 2022), and monitoring programs for rainfall isotopes (Zwart et al., 2018) and pollen (Wall, 2024).

Not all sites yielded decent records, even after assessing them using the 'Water observations from Space' dataset to identify those that appeared not to have dried out over the last 30 years, for which satellite images are available. Ten years and cores from 26 sites later, we have expanded knowledge of environmental change across the northern savannas (Table 1 and Figure 2). Many records from the other lake sites (and one archaeological site) cored in the last decade by JCU staff have been published or are being worked up for publication, as indicated in Table 1. Many extend beyond the Holocene and several beyond the Last Glacial Maximum. Eight postgrad students successfully graduated backed by CABAH resources and training.

By far, the site that keeps on giving is Girraween Lagoon, ironically only 20km outside Darwin in Howard Springs. It was where the crocodile attack scene in *Crocodile Dundee* was filmed and part of the mechanism that allowed the beast to lunge at Linda Koslowski is still visible in a shallow excavation near the raft launching point on the western side of the Lagoon. The Lagoon is a sinkhole infilled by 18 m of alternating organic and clay rich sediment that provides a continuous record spanning the last 150,000 years. Cores from the lake have provided detailed palaeoecological, palaeohydrological records as well as demonstrating that Indigenous management of fire regimes is detectable from at least 11,000 years ago, and probably earlier.

Girraween Lagoon was also the focus of several CABAH Education and Engagement Program activities. The Darwin area became a hub for filming, industry presentations, festival participations, gallery exhibitions, school visits, and ABC media interest. *The Earth Above: A Deep Time View of Australia's Epic History (The Girraween Lagoon Story)* went on display at the Northern Territory Museum as a part of the Darwin International Film Festival. Likewise, a short film explaining the Larrakia *Seven Seasons* calendar, is now available online at www.youtube.com/watch?v=BGSwtgwXorQ. The audio-video artwork *Where Lakes Once Had Water* (part of the CABAH Art Series) has attracted diverse audiences nationwide, sparking conversations that touched on both art and science. Attending the World Science Festival in Brisbane also proved successful (if not chaotic!) in sharing with the public what we do, how and why: epicaustralia.org.au/video/street-science.

Figure 1: A) RV *General Lee* on Kinrara Lagoon; **B)** RV *My Little Pony* on Girraween Lagoon; **C)** Raft disassembled and packed on trailer for transport at Girraween Lagoon; **D)** Raft not used, just backed the vehicle as fast and as far as it would go into Numbulwar Lagoon; **E)** Raft components helicoptered into Kandimalal-Wolfe Creek Crater and assembled upside down (because there was no water).

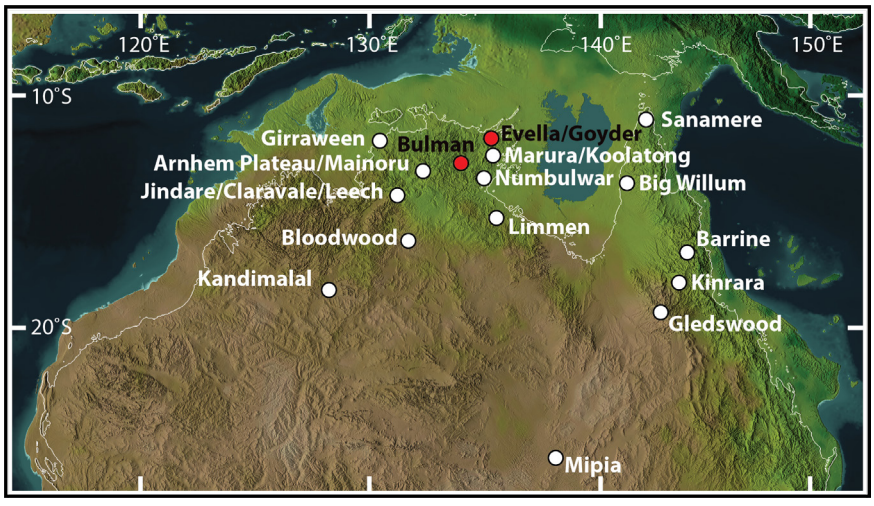

Figure 2: Location of sampled areas in Table 2. Sites in white have preliminary or published records, sites in red were cored but have not had further work conducted.

Figure 3: CABAH education and outreach activities. **A)** Brisbane World Science Fair 'How to tell the weather in an ice age; **B)** Children watching *The Earth Above* in an inflatable dome at the Museum and Art Gallery of the Northern Territory; **C)** Pollen microscopy at the Brisbane World Science Festival; **D)** Children watching the 'Pleistocene Weather Report' at the World Science Festival; **E)** Martin Potter recording Larrakia Elder Lorraine Williams for the Larrakia seven seasons weather calendar video.

We thank those who participated in the months of fieldwork involved – the start of each marked by the classic line from Blackhawk Down 'No one gets left behind...' and the progress of each marked by much sweat and occasional blood, but relatively few tears. Nights were spent watching movies on a fluttering bedsheet suspended between convenient trees (where possible). Those individuals in alphabetical order are: Saroj Bhattarai, Mel Boer, Michael Brand, Sean Campbell, Rainy Comley, Alan Cooper, Kalu Davies, Xennephone Hadeen, Jordahna Haig, Raul Hernandez Font, Emil Holt, Lindsay Hutley, Julie James, Michael Laws, Ting Li, Jon Nott, Emma Rehn, Peter Ridd, Maria Rivera-Araya, Bert Roberts, Gustavo Saiz, Michael Santarossa, Doug Sberna, Russell Singleton, Bob Wasson, James Whinney, Chris Wurster, Mojca Zega, and Cos Zwart.

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Table 1: Individual site details for areas included in Figure 2. Basal ages, where known, are reported in ka.

SITE NAME	LAT. (S)	LONG. (E)	BASAL AGE (KA)	REFERENCE OR DESCRIPTION
Girraween	12.52	131.08	~150	Rowe et al. (2019; 2021; 2024); Wurster et al. (2021); Bird et al. (2024); Hadeen et al. (2025)
Evella	12.51	135.80	?	Core collected, unopened
Goyder-2	12.94	135.20	?	Core collected, unopened
Jindare-K6d	13.99	131.57	?	Core collected, unopened
Jindare-K6	13.99	131.57	?	Core collected, unsuitable
Jindare-K6e	13.99	131.57	>100	Reynolds (2024)
Jindare-K4	14.05	131.62	?	Core collected, unopened
Claravale-K3b	14.19	131.70	?	Core collected, unopened
Claravale-K3	14.19	131.70	?	Core collected, unopened
Claravale-K3c	14.19	131.70	?	Core collected, unopened
Leech	12.71	135.73	?	Core collected, unopened
Bloodwood	15.20	132.72	>100	Reynolds (2024)
Bulman	13.52	134.51	?	Core collected, unopened
Mainoru-2 A3	13.72	133.89	?	Surface sediments only
Mainoru-3 A4	13.67	133.77	?	Surface sediments only
Mainoru-5 A6	13.75	132.56	?	Surface sediments only
Arnhem Plateau	13.69	133.56	~11	Rowe et al. (submitted)
Marura	13.41	135.77	~15	Rehn et al. (2021b); Rowe et al. (2023)
Koolatong-2	13.52	134.51	N/A	No sedimentary record
Numbulwar-1	14.20	135.72	~20	Analysis in progress; K. Boyd
Limmen	15,46	135.42	0.49	Rowe et al. (2023)
Kandimalal	19.17	127.79	~70	Analysis in progress; F. Boesl
Sanamere	11.12	142.36	~33	Rehn et al. (2021a); Rivera-Araya et al. (2022; 2023)
Big Willum	12.65	141.99	~ 3	Rehn et al. (2021a)
Barrine	17.25	145.63	~18	Li et al. (2022; 2023; 2024)
Kinrara	18.50	145	~30	James et al. (2024); Comley (2024)
Gledswood	19.52	143.2	~30	Zega (2024)
Mipia	24.92	139.49	~450	Singleton (2025)

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OCTOPUS AND SAHUL DATABASES

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Over the past eight years, CABAH members have been developing OCTOPUS, a cloud-based, open-access platform that incorporates geological, palaeontological, and archaeological data. Each database within OCTOPUS has been gathered from a broad array of sources, including published works and grey literature, which lack consistent reporting standards. The databases have been standardised, with detailed metadata fields specific to each sub-collection, making data review, modelling, and assessment of chronometric robustness simple.

OCTOPUS was created to address issues of visibility and access for legacy data that can be scattered across a wide range of literature that may be rarely cited, unpublished, or unavailable in digital formats. OCTOPUS helps address these issues by providing a single comprehensive source for age determinations from Sahul with standardised metadata. It is hoped that the development of these databases will make data access easier for researchers, enabling important syntheses and inclusion of Australian data in global comparison studies.

After the initial development of purely chronological data collections (SahulSED and SahulArch), additional datasets of palaeoenvironmental and palaeontological trait-based data were developed. Ongoing updates of the core collections make the database a valuable legacy product of CABAH, informing future archaeological, palaeoenvironmental, and sedimentary research in Australia and New Guinea.

CORE COLLECTIONS

- **CRN** contains cosmogenic radionuclide (^{10}Be and ^{26}Al) denudation rates from around the globe (Codilean et al., 2018; Codilean et al., 2022).
- **SahulArch** contains radiocarbon, OSL, and TL dates from archaeological sites in Australia and New Guinea (Sahul). Site locations are randomly obfuscated within a 25-kilometre radius to protect potentially sensitive cultural knowledge (Saktura et al., 2023).
- **SahulSED** contains OSL and TL ages from sedimentary archives (fluvial, aeolian, and lacustrine) in Australia and New Guinea (Sahul) (Cohen et al., 2021).
- **SahulCHAR** contains fire proxy data and age determinations from sedimentary archives in Australia, New Guinea, and New Zealand (Rehn et al., 2025).
- **The Indo-Pacific Pollen Database** contains microfossil, charcoal, and geochemical data, creating the largest collection of palaeoecological data for the Indo-Pacific region (Herbert et al., 2025).
- **SahulTraits** contains georeferenced data of traits for all recognised terrestrial mammals, birds, amphibians, and reptiles in Sahul.

PARTNER COLLECTIONS

- **FosSahul** contains radiocarbon, OSL, U-series, AAR, and ESR ages from non-human vertebrate fauna fossil sites in Australia and New Guinea (Sahul). Site locations are randomly obfuscated within a 25-kilometre radius (Peters et al., 2019).
- **ExpAge** contains cosmogenic radionuclide (^{10}Be and ^{26}Al) ages from glacial samples around the globe.

OCTOPUS is cloud-based and open access, meaning users can access data via a web interface or directly through software such as QGIS or R using the Web Feature Service. The latest information on accessing OCTOPUS can be found on the Data Access page. This includes guides on using the Web Feature Service through third-party software, as well as features and functions of the OCTOPUS web interface.

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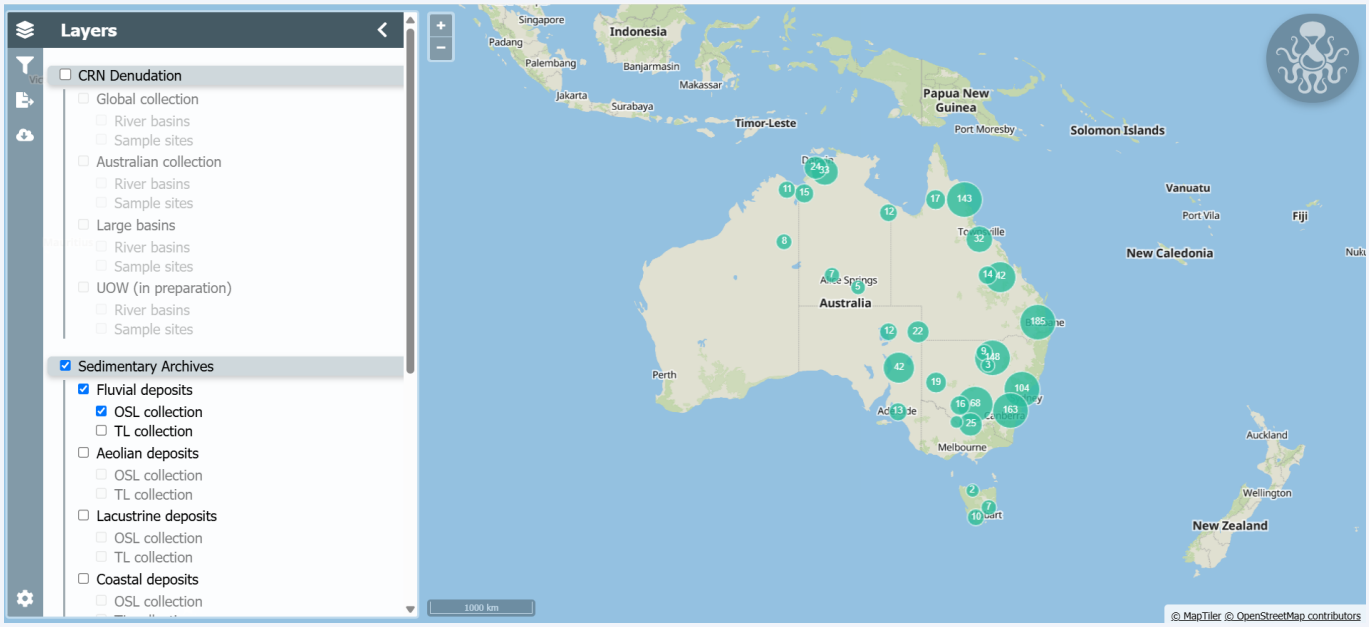
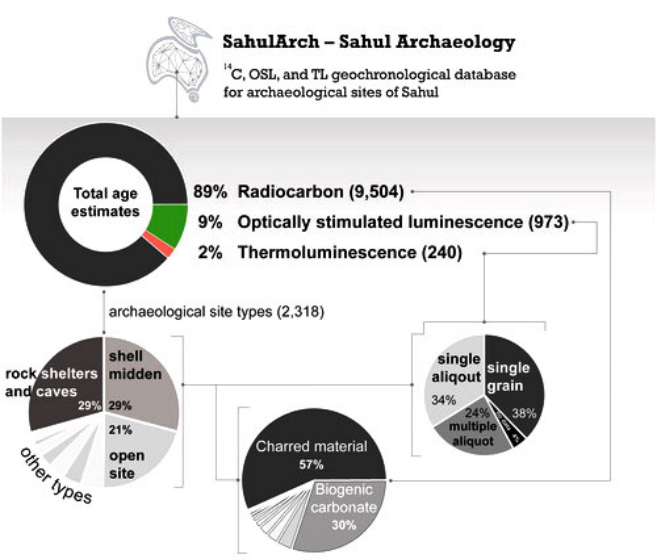
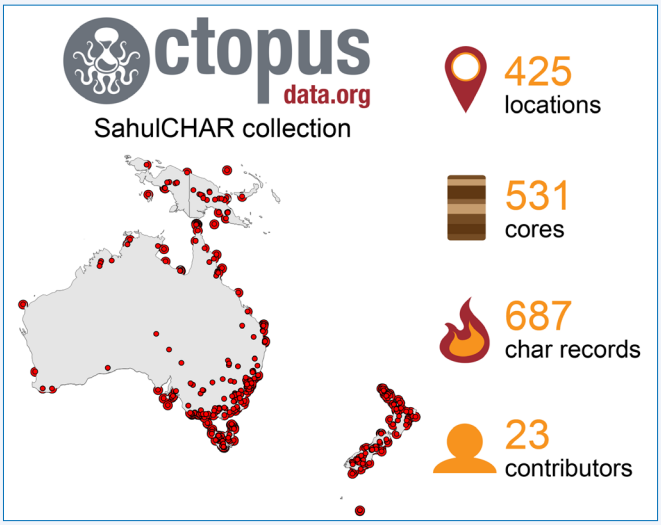


Figure 1: Geographical distribution of the data assets associated with the SahulSED fluvial OSL ages across Australia. The circles (and numbers, if applicable) represent the number of ages in specific locations.

Right Top – Figure 2: Graphical abstract of Saktura et al. (2023) demonstrating the number, dating technique, and site type of the data assets for SahulArch.

Right Bottom – Figure 3: Graphical abstract of Rehn et al. (2025) showing the location of char records, number of individual records, and contributors to the database.





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EXPLORING MICROBIAL RESPONSES TO FIRE

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Fire is a fundamental aspect of Australia's natural environment, shaping ecosystems and influencing biodiversity for millennia. However, the long-term impacts of fire on microbial communities—the often-overlooked drivers of ecosystem functions—remain poorly understood. My research, supported by the ARC Centre of Excellence for Australian Biodiversity and Heritage (CABAH) through its Future Leaders Program, aims to address this critical knowledge gap.

My project, titled "Reconstructing Long-Term Records of Microbial Responses to Fire in Australia," investigates how microbial communities adapt to changing fire regimes. This research combines modern and ancient environmental DNA analysis with detailed fire histories to explore how microbial species in soil and sediment have responded to past fire events. By characterising the taxonomic profiles of these communities across southern Australia, including Tasmania and South Australia, I aim to establish a baseline for understanding microbial responses to recent megafires. Through this approach, I have recovered fragments of ancient microbial genomes, providing a unique window into how microbial communities have evolved in response to historical fire events. This long-term perspective is essential for identifying the ecological consequences of modern megafires and anticipating future impacts on biodiversity.

This research is not only about documenting microbial diversity but also about uncovering the adaptive traits that have enabled certain species to persist in fire-affected environments. Understanding these traits can provide critical insights into ecosystem resilience and inform effective fire management strategies.

The CABAH Future Leaders Program has been a transformative experience in my career, offering essential funding and opportunities for professional growth. The program has allowed me to refine my leadership skills by mentoring two research assistants in advanced environmental genomics, including laboratory techniques and bioinformatics. This experience has significantly broadened the scope of my research and enhanced my ability to lead independent studies in environmental microbiology, including managing research teams.

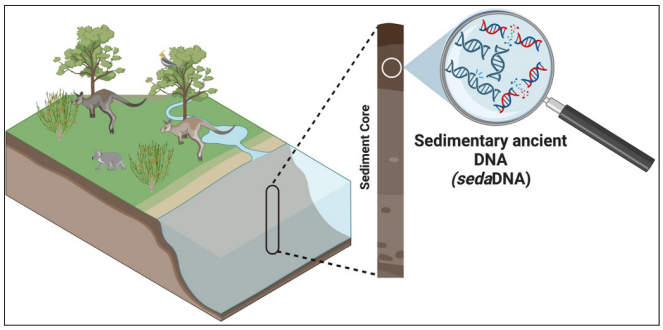

Figure 1: Sedimentary DNA records comprise a mixture of genetic materials from organisms that lived within the lake (autochthonous material) and those from the surrounding area and its catchment (allochthonous material). Sedimentary ancient DNA (sedaDNA) may be poorly preserved due to its age.

Figure 2: Dr. Vilma Pérez sub-sampling sediment cores for sedaDNA analysis. (Photo credit: Jacqueline Wales).

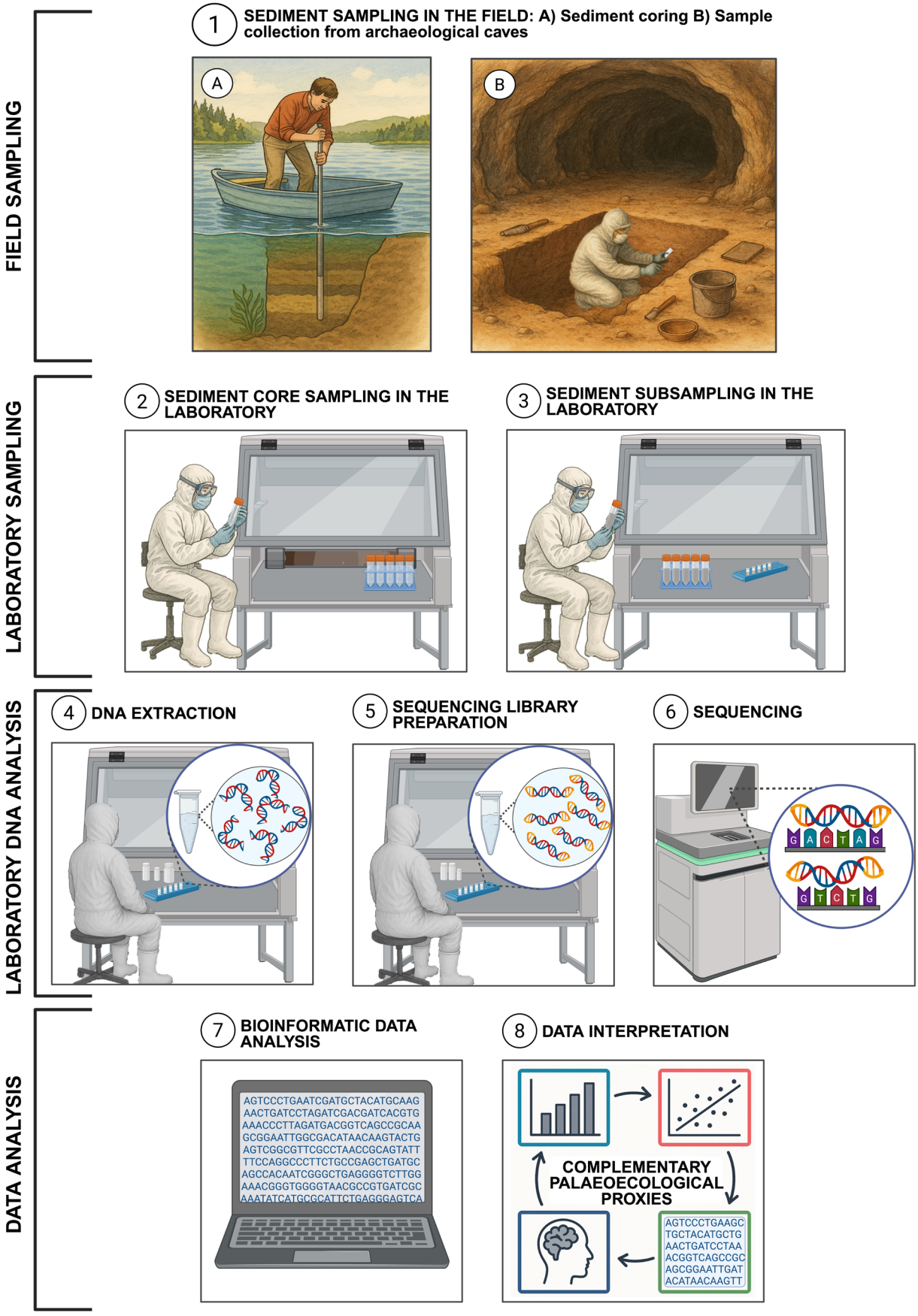

Figure 3: Sedimentary DNA workflow for sequencing-based analyses.

TAXONOMIC AND TROPHIC RESTRUCTURING SHOW MAMMALS ARE UNUSUALLY VULNERABLE IN SAHUL'S LARGE-BODIED ANIMAL COMMUNITY

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ABSTRACT

Communities of large-bodied animals have changed in composition since the Late Pleistocene, triggering flow-on effects for modern ecosystems. However, the details of these changes remain unclear. We examined the composition of Sahul's large (>10 kg), non-marine tetrapod community between 100,000 years ago (Late Pleistocene), 1788 (prior to European invasion), and today by quantifying changes in species richness and the proportion of species in different trophic guilds and taxonomic classes. Richness fluctuated through time (between 103 and 37 species), with mammals and herbivores most affected. Most herbivores and invertivores were mammals (>95% and 100%, respectively), most carnivores were reptiles (≥79%), and most omnivores were birds (>62%). In the Late Pleistocene, extinction risk differed among trophic guilds and taxonomic classes — mammals and herbivores were over-represented among extinctions. Although mammals remain the most vulnerable class, post-1788 patterns do not show large differences among taxonomic or trophic groups. Community composition also shifted due to the arrival of species: two large species arrived before European invasion, and 21 have been introduced since. These results indicate substantial changes in the trophic and taxonomic composition of Sahul's large-bodied fauna, pointing to shifts in the structure and function of its ecological communities.

INTRODUCTION

Extinction, migration, and speciation have caused pronounced changes in the species composition of ecological communities, from microbiomes to continental and global species assemblages (Lomolino, 2020). Certain groups of species can be over- or under-represented in such changes. For example, South American mammals were the group most impacted by the invasion of North American mammals during the Great American Biotic Interchange, which began approximately 3 million years ago (Carrillo et al., n.d.; Webb, 1991; Goin, 2023). Similarly, Late Pleistocene extinctions that occurred 60,000 to 12,000 years ago mostly involved large-bodied species (Johnson, 2006; Koch & Barnosky, 2006), and the End-Cretaceous mass extinction ~66 million years ago shaped mammal communities by selectively removing dietary specialists such as strictly carnivorous or herbivorous species (Wilson, 2013). Importantly, changes in both absolute species richness and biases in which groups of species increase or decrease in abundance and richness can impact the structure and function of ecological communities (Hillebrand et al., 2008; Hobbs et al., 2024).

Large-bodied animals play important roles in their communities involving, among other processes, nutrient cycling, ecosystem engineering, and propagule dispersal (Ripple et al., 2015). However, large body size is also associated with increased vulnerability to extinction (Atwood et al., 2020). Indeed, the modern decline in large animals continues a trend that has ensued at least since the Late Pleistocene (Payne et al., 2023). Humans have contributed to the disruption of large animal communities by causing extinctions and intentionally introducing species (Bull & Maron, 2016; Tomlinson et al., 2025), and natural changes in climate likely also contributed to extinctions in the Late Pleistocene (Saltré et al. 2019; Hocknull et al., 2020). These changes in large-animal assemblages have had lasting effects on ecological communities (Svenning et al., 2024). For example, population declines and extinctions of megaherbivores

have had strong effects on vegetation structure and dynamics via top-down processes and left many plant species without suitable animals to disperse their seeds (Johnson, 2009; Hyvarinen et al., 2021; Svenning et al., 2024). While the consequences of the loss of large species have been acknowledged, many likely remain unknown in part because we still have a poor understanding of how large-animal communities have changed over the last 100,000 years (i.e., the period when *Homo sapiens* spread over most of the planet; Saltré et al., 2024).

Sahul, the landmass comprising Australia, New Guinea, and nearby islands joined during periods of lower sea level than today, has experienced changes in its large-animal community over the past 100,000 years (Johnson, 2006; Saltré et al., 2016; Bradshaw et al., 2021; Svenning et al., 2024). Late Pleistocene extinctions 20,000 to 50,000 years ago removed most terrestrial animals weighing >40 kg (Johnson et al., 2016), and other species have gone extinct or been introduced since European colonisation in the 18th century (Johnson, 2006; Woinarski et al., 2015, 2019). However, an overall quantification of changes through time in the composition of Sahul's large-bodied, terrestrial fauna — examining changes in taxonomic and trophic composition — is still lacking. Such information is needed to understand how community dynamics have changed in the past and how they could change in the future, as well as predicting future dynamics given the legacy of past extinctions and introductions.

To address this gap, we examined shifts in the composition of the large tetrapod (>10 kg) community across Sahul over the past 100,000 years (encompassing human arrival approximately 65,000 years ago (Clarkson et al., 2017) and European invasion that started in 1788). More specifically, we tested how the numbers of species in different taxonomic classes and trophic guilds have fluctuated through time, and the prevalence of species in these groups among extinct, International Union for the Conservation of Nature (IUCN)-listed, and introduced species. We hypothesise that in Sahul:

(1) Most large animals are herbivorous mammals, reflecting the global pattern (Ripple et al., 2019; Atwood et al., 2020).

(2) Mammals have been more vulnerable to extinction than large animals from other taxonomic classes because of their high resource requirements (linked to endothermy and large body size) and relatively limited dispersal ability (compared to birds).

(3) Carnivores have been more vulnerable to extinction than large animals from other trophic guilds because of their higher resource requirements and high trophic position (which makes them sensitive to perturbation across multiple trophic levels).

(4) Most large animals that arrived in Sahul in the past 100,000 years are herbivorous mammals, reflecting both the species richness of large herbivorous mammals and a human preference for deliberately introducing them (Turbelin et al., 2017).

(5) There is a non-independent relationship between taxonomic class and trophic group because taxonomic classes differ in their suitability for various trophic strategies due to differences in morphology, physiology, and evolutionary history.

METHODS

We restricted our focus to non-marine tetrapods that regularly reach an adult body mass over 10 kg and that have been established (i.e., breeding across multiple years) in Sahul in the past 100,000 years. We chose a 10 kg threshold rather than the usual (but arbitrary) ~40 kg threshold used for defining large animals/megafauna, because it expands the number of species we could consider and thereby provides a broader and more holistic view of changes in the community of large animals (there are only ~12 native species — including humans — >40 kg in Sahul today). A similar threshold has been used in other recent works (e.g., Svenning et al., 2024). Using databases, scientific literature, and expert opinion (Wilman et al., 2014; Garnett et al., 2015; Myhrvold et al., 2015; Sterli, 2015; Smith et al., 2019; Hocknull et al., 2020; Mather et al., 2024; McInerney et al., 2024; Mudge et al., unpublished data; E. Vanderduys, personal communication), we built a species list of these large animals, assigning each to a trophic guild (carnivore, herbivore, invertivore, or omnivore), taxonomic class (Aves, Reptilia, or Mammalia), and an IUCN status for surviving species (Red List; IUCN, 2025). We also identified which species were present 100,000 years ago (Late Pleistocene), which arrived since then but before European invasion in the 18th century, and which were introduced since European arrival. Similarly, we categorised extinctions as those that occurred before versus after European invasion (i.e., between 100,000 years ago and 1788 versus since 1788).

With this species list, we assessed how the number of large animals in different trophic guilds and taxonomic classes changed in Sahul over time. More specifically, we compared species richness at three time points: 100,000 years ago, 1788 (prior to European invasion of Australia, which predates European arrival in New Guinea), and the current time (i.e., 2025). We chose these points in time to capture species richness (*i*) before the Late Pleistocene megafauna extinctions, (*ii*) immediately prior to European arrival and the massive land-use changes that ensued quickly thereafter, and (*iii*) after more than 230 years of land-use change following European arrival, settlement,

and expansion. For the current time, we compared species richness with and without recently introduced species (introduced since 1788).

To investigate extinctions prior to European invasion, we calculated the number of species that went extinct in each trophic guild and taxonomic class between 100,000 years ago and 1788 (all extinctions of large animals in Sahul in this period are thought to have occurred over 20,000 years ago in the Late Pleistocene; Letnic, 2000; Woinarski et al., 2015; Mansergh et al., 2022; Prideaux et al., 2022). However, there are likely to be more large species that went extinct in the Late Pleistocene that are yet to be discovered, and there could be spatial, taxonomic, and trophic biases in this missing information (Hocknull et al., 2020). We assessed species vulnerability since 1788 by combining species that went extinct since that time (i.e., only two large-bodied species: the thylacine *Thylacinus cynocephalus* and the toolache wallaby *Notamacropus greyi*) with those that are currently listed as Critically Endangered, Endangered, Vulnerable, or Near Threatened (i.e., those not assigned as Least Concern by the IUCN). We then assessed whether the proportion of species we classified as threatened according to the combined criteria above varied among trophic guilds and taxonomic classes. Due to uncertainty of status, we excluded two species from analysis, one that was Data Deficient (Boelen's python *Simalia boeleni*) and another that has not had its conservation status assessed by the IUCN (Hall's New Guinea crocodile *Crocodylus halli*). Both these species are carnivorous reptiles.

We tested whether any trophic or taxonomic groups were over- or under-represented among the extinctions that occurred between 100,000 years ago and 1788 (most or all of which occurred in the Late Pleistocene) using randomisation tests. To do this, we identified the number of species that went extinct in that period and then randomly sampled that number of species from the list of species present 100,000 years ago (i.e., including species that persisted and those that subsequently went extinct). We resampled 10,000 times, at each iteration recording the number of species in each trophic guild and taxonomic class in the resampled set. Then, we calculated the proportion of iterations the number of species in each trophic guild or taxonomic class in the sample was greater than or equal to the observed number of extinctions in those groups, and the proportion of iterations the number of species in each trophic guild and taxonomic class in the sample was less than or equal to the number of observed extinctions in each group. For each trophic guild and taxonomic class, we multiplied the smaller of these two proportions by two (because it is a two-tailed test for both over- and under-representation) to calculate the probability of the observed number of extinctions in each group if extinctions were random across groups. We used the same approach to assess changes since European invasion, testing whether any trophic or taxonomic groups were over- or under-represented among the species classified as threatened or extinct.

RESULTS

Over the past 100,000 years, there have consistently been more large mammals than large reptiles or large birds in Sahul (Figure 1a,c). However, the number of large mammals has fluctuated more through time than has the number of large birds and reptiles; species richness of mammals varied between consecutive time points by up to 75%, whereas bird and reptile species richness varied by <37% (Figure 1a,c). Most large animals in Sahul in the Late Pleistocene, but prior to human arrival, were herbivores (Figure 1b). After the Late Pleistocene extinctions and the arrival of dingoes between 3,500 and 10,000 years ago, herbivore diversity declined, and species richness of carnivores equalled that of herbivores (Figure 1b). If we only consider native species (including dingoes and humans), at the present time there are equal numbers of large carnivores and herbivores, and fewer omnivores and invertivores (Figure 1d). However, if we also include recently introduced species, there are currently more herbivores than any other trophic guild (Figure 1d).

Although there have been consistently more species of large mammals than of large birds and reptiles over the last 100,000 years, mammals are not the most species-rich group in each trophic guild (see supplementary Figure S1 and Table S1). Most large herbivores and invertivores in the past and today are mammals (95% – 100% of herbivores, and 100% of invertivores), whereas reptiles were consistently the most speciose class in the carnivore group (making up 79% – 93% of species in this group), and birds were consistently the most species-rich class in the omnivore category (63% – 80% of species).

Between 100,000 years ago and 1788, most large mammals went extinct, whereas most large birds and reptiles persisted (Figure 2a). Randomisation tests showed that mammals were over-represented in these extinctions ($p < 0.0001$), whereas reptiles were under-represented ($p < 0.003$). The proportion of birds that went extinct was similar to that of reptiles (Figure 2a), but randomisation tests did not detect that birds were under- or over-represented among extinct species ($p = 0.21$), likely due to the small sample size of this group. The only two species >10 kg that have gone extinct in Sahul since 1788 (i.e., European invasion) were mammals (*Notamacropus greyi* and *Thylacinus cynocephalus*). When these extinctions are combined with IUCN assessments, mammals remain the most threatened group (Figure 2c).

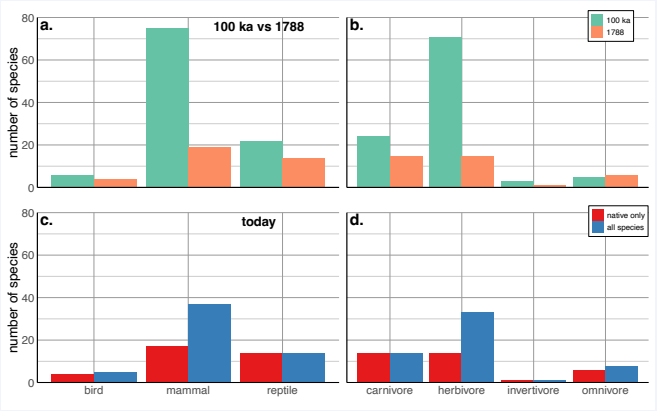

Figure 1: Species richness of large (>10 kg), non-marine tetrapods found in Sahul at three time points: 100 ka, 1788 (the time of European invasion), and today (2025). Panels **a)** and **b)** compare species richness at 100 ka (Late Pleistocene) versus in 1788. Panels **c)** and **d)** compare present-day richness, considering only native species versus including recently introduced species. Plots on the left show species richness among taxonomic classes whereas plots on the right show species richness among trophic guilds.

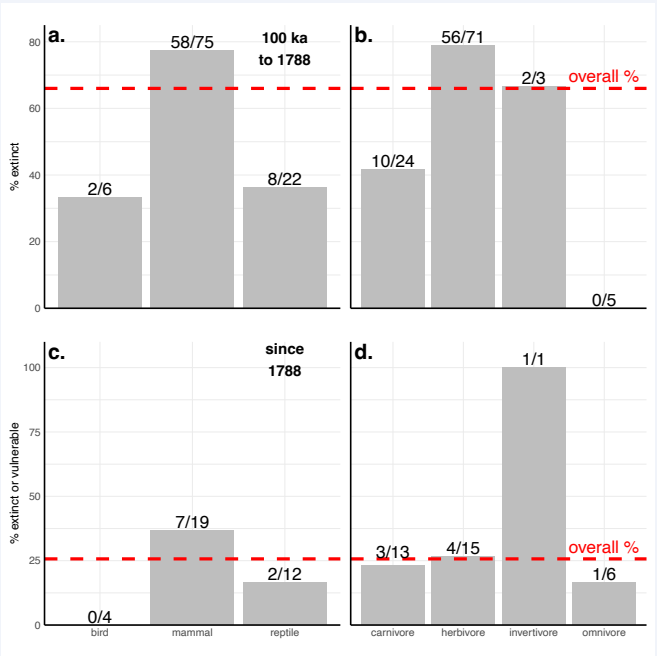

Figure 2: The percentage of large (>10 kg), non-marine tetrapods that went extinct in Sahul between 100,000 years ago (Late Pleistocene) and 1788 (top row), and the percentage of large species that have gone extinct since European invasion in 1788 or have a current IUCN status above Least Concern (bottom row). Plots on the left show how these percentages vary among taxonomic classes, whereas plots on the right show how they vary among trophic guilds. Red dotted lines indicate the overall percentage of species that went extinct (top row) or the overall percentage of species with an IUCN status above Least Concern (including recently extinct species; bottom row).

However, randomisation tests suggest that none of the taxonomic classes is over- or under-represented among threatened large animals in present-day Sahul ($p > 0.3$ in all cases).

Most large herbivores and invertivores went extinct before between 100,000 years ago and 1788 (Figure 2b), whereas most carnivores and all omnivores persisted until 1788 (Figure 2b). Randomisation tests indicate that herbivores were over-represented among the extinctions occurring between 100,000 years ago and 1788 (Figure 2b; $p = 0.0003$), carnivores and omnivores were under-represented among those extinctions (Figure 2b; $p < 0.02$ in both cases), and invertivores were neither over- nor under-represented ($p > 0.05$). The western long-beaked echidna (*Zaglossus bruijni*) was the only large invertivore that persisted through that period. It is extant today but is classified as Critically Endangered on the IUCN Red List (IUCN, 2025). Most large species in other trophic guilds have persisted since 1788 and are classified as Least Concern by the IUCN (Figure 2c). While omnivores have the highest proportion of species classified as Least Concern (Figure 2d), randomisation tests suggest none of the trophic guilds is over- or under-represented among threatened species today ($p > 0.6$ in all cases). The two large species that went extinct since European arrival — *Notamacropus greyi* and *Thylacinus cynocephalus* — include a herbivore and a carnivore, respectively.

Most large species that have been introduced since European invasion are herbivorous placental mammals (see supplementary Table S1). Of the 21 large-bodied species introduced, 20 are placentals (19 herbivores and one omnivore) and one is an omnivorous bird (mute swan *Cygnus olor*). No large reptiles have been introduced, nor any large carnivores (unless the domestic dog is treated as a separate species to the dingo). All large mammals in Sahul 100,000 years ago were marsupials (72 of 75) or monotremes (3 of 75), whereas 59% of extant large mammal species in Sahul today are placentals (22 of 37).

DISCUSSION

The overall species richness and the proportion of species in different trophic guilds and taxonomic classes has shifted substantially in Sahul's large-bodied animal community over the past 100,000 years (Figure 3). These changes have disproportionally affected herbivorous mammals, though there have also been declines in species richness in other trophic and taxonomic groups. By quantifying these changes, our study sheds light on broader ecological shifts, and emphasises the unique challenges faced by native species persisting in Sahul.

Although there are far more species of reptiles and birds in Sahul than mammals (Dickman, 2018), large mammals have consistently outnumbered large

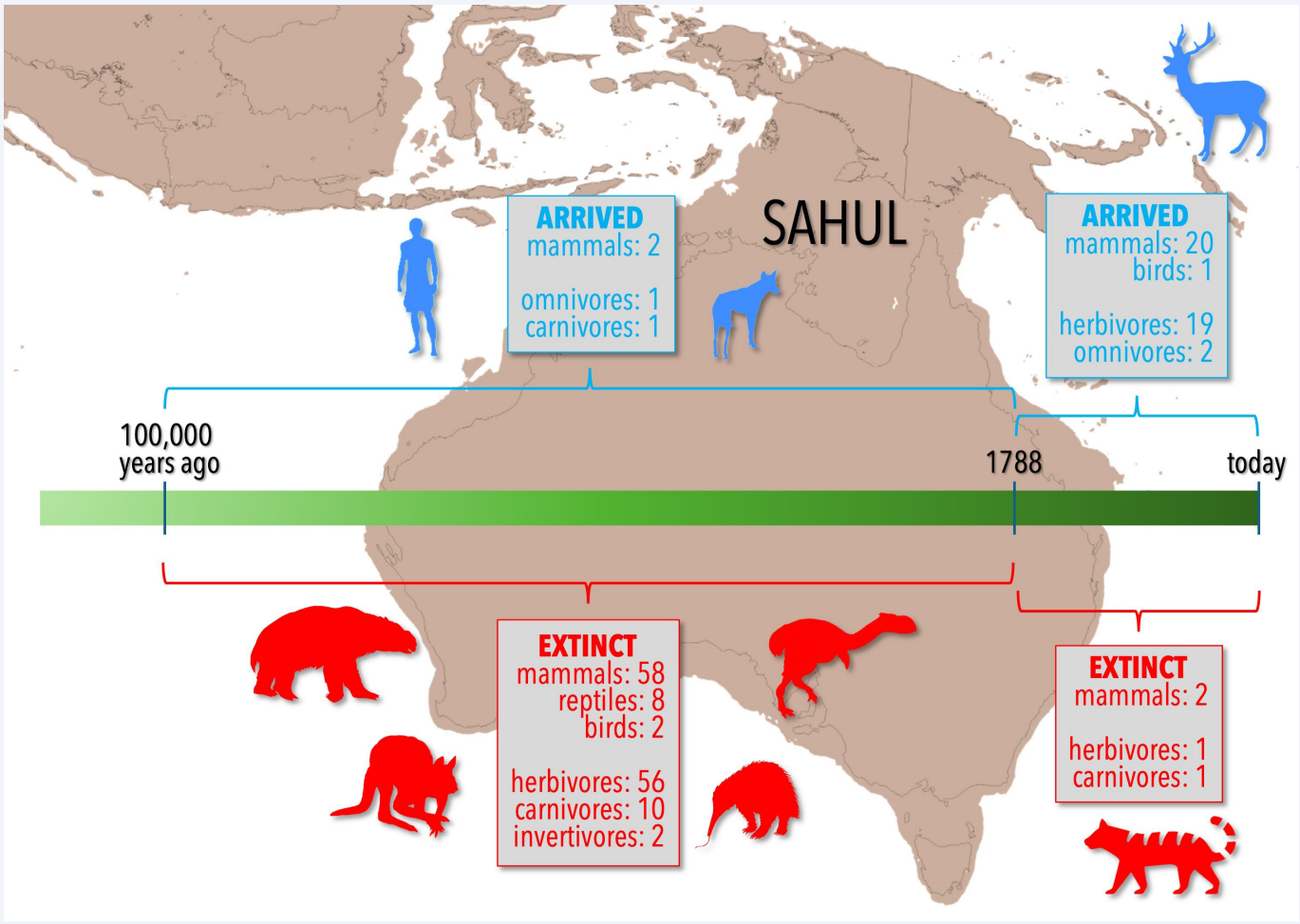

Figure 3: Timeline displaying the change in Sahul's large-bodied tetrapod fauna since the Late Pleistocene

reptiles and large birds since the Late Pleistocene — and likely for much longer (Archer et al., 2023; Benevento et al., 2023; Figure 1). However, the number of large mammals, particularly herbivores, has varied more over time than that of reptiles and birds, due to many extinctions in the Late Pleistocene and since European invasion (Figure 2), and the arrival of new species (Figure 1c,d). Similarly, large-bodied animal faunas on other continents are dominated by mammals, and herbivores in those communities have also experienced high extinction rates since the Late Pleistocene (Ripple et al., 2015, 2019; Atwood et al., 2020).

The vulnerability of herbivores in Sahul (Figure 2a) contrasts with our hypothesis that carnivores would be the most at-risk trophic guild, suggesting that cumulative bottom-up effects across trophic levels do not explain the observed extinction pattern. Instead, direct effects may be more important (Scherber et al., 2010). As with herbivores, Sahul's large invertivores – all of which were mammals – were vulnerable across both periods (Figure 2b,d). Non-marine mammals that specialise on small prey items such as invertebrates are typically small-bodied themselves (Carbone et al., 2007). The vulnerability of large invertivores in Sahul could therefore reflect the challenge of sustaining a large, endothermic body on small prey (Cooke et al., 2022). In contrast to the vulnerability of dietary specialists, we found that omnivores were the least at-risk trophic guild across both periods, suggesting that trophic flexibility might confer resilience in these species (Edwards et al., 2013).

Several factors have been identified to contribute to the vulnerability of large mammalian herbivores, including their sensitivity to vegetation and land use change; desirability as prey for human hunters (including as trophies; Johnson et al., 2010); overlap in habitat use with humans and domesticated animals; and traits associated with large body size and endothermy such as slow life history, high resource requirements, and low population density (Turkington, 2009; Ripple et al., 2015). In the case of Sahul's large mammals, the arrival of humans in the Late Pleistocene exposed many species to a new predator, a change that might have been particularly

challenging for large megafauna that had previously experienced low predation pressure (Llewelyn et al., 2021). Changes in climate and vegetation, potentially in combination with increased predation pressure, could also have disproportionately affected large mammalian herbivores at that time (Saltré et al., 2019; Hocknull et al., 2020; Llewelyn et al., 2021). Moreover, the challenges faced by large, herbivorous mammals continue in Sahul today; almost all recently introduced large species are herbivorous mammals, applying pressure on their native counterparts through competition and habitat modification (Pringle et al., 2023).

Mammals of smaller body sizes are also more threatened in Sahul — 34 of the 48 tetrapods that went extinct in Australia since European invasion have been mammals (including small and large species; Woinarski et al., 2019). However, unlike the pattern observed Sahul — where mammals have tended to be more threatened than birds and reptiles (Figure 2; Walsh et al., 2013; Geyle et al., 2018; Woinarski et al., 2019) — Atwood et al. (2020) found globally and across body sizes, proportionally more reptiles has gone extinct in the past 500 years, and proportionally more surviving reptiles are listed as threatened, compared to mammals and birds. Birds, mammals, and reptiles differ in their energetic demands, dispersal capacity, and thermoregulatory strategies, which likely influence their vulnerability to different disturbances (Buckley et al., 2012). The relatively low energy requirements of reptiles and the high dispersal capacity of birds might partly explain their greater resilience in Sahul compared to mammals (Pough, 1980; Isaac et al., 2009). While the long evolutionary isolation of many of Sahul's mammals has been invoked to explain their heightened vulnerability (Woinarski et al., 2015), this does not account for the relative persistence of other taxa, nor the fact that mammals arriving more recently in Sahul (e.g., native rodents) also have elevated extinction risk (Roycroft et al., 2021). Additionally, there appears to be no relationship between demographic susceptibility to extinction and the extinction chronology observed in Sahul since the arrival of humans in the Late Pleistocene (Bradshaw et al., 2021). Further investigation is needed to understand why mammals in Sahul have been so vulnerable, and why this region differs from global patterns in class-specific extinction risk.

Changes in the number and proportion of large species in different trophic and taxonomic groups have likely affected the structure and function of ecological communities in Sahul (Llewelyn et al., 2021; Adeleye et al., 2023; Pires, 2024). Large predators structure ecological communities via top-down control, altering ecosystems through processes such as mesopredator release and shifts in predation pressure on other species. Indeed, the loss of large predators such as *Thylacoleo carnifex* and giant varanid lizards could have reduced top-down control on smaller predators (Flannery, 1994). This might have made small vertebrates more vulnerable to newly arrived mesopredators such as cats and foxes, which have had a devastating impact on Australia's terrestrial biodiversity (Glen & Dickman, 2005; Philippe Lesaffre et al., 2025). Similarly, megaherbivores play a unique and irreplaceable role in their communities in terms of nutrient cycling, seed dispersal, control of vegetation structure and dynamics (including carbon sequestration and storage), and maintenance of biodiversity (Hyvarinen et al., 2021; Pringle et al., 2023). Thus, the loss of large, native herbivores and carnivores, along with the arrival of new species, has likely reshaped Sahul's ecological communities across all trophic levels, from primary produces to apex predators (Johnson, 2009). Supporting this conclusion, long-term sediment/pollen records indicate changes in vegetation following shifts in the composition of Sahul's animal community in the Late Pleistocene (Rule et al., 2012; Adeleye et al., 2023).

The observed changes in the composition of Sahul's animal community have consequences for ecological communities in the future. For example, past extinctions might have reduced the resilience of communities through the loss of functional redundancy, making them more prone to ecological cascades (Pires et al., 2015; Strona, 2022). Declines in functional diversity and redundancy due to these extinctions might have been partly offset by the arrival of new species (Figure 1) that fulfill some of the ecological roles left vacant or eroded by past extinctions (Wooster et al., 2024). However, these newly arrived species have severely affected native communities by altering habitats and causing population declines of native species (Stobo-Wilson et al., 2020). Indeed, recently introduced species have been implicated in many extinctions, and the long-term consequences of their establishment in Sahul are yet to be fully realised (Woinarski et al., 2015).

Research on large-bodied animal communities and how they have changed since the Late Pleistocene has focused on mammals (Clark & May, 2002; Johnson, 2006; de Miranda, 2017). This focus likely reflects (*i*) the greater species diversity of large mammals compared to that of other taxonomic classes, (*ii*) the pronounced declines in their abundance and diversity (Woinarski et al., 2015), and (*iii*) a human and research bias towards mammals and birds (Hecnar, 2009; Titley et al., 2017). However, because most large herbivores are mammals, this taxonomic bias has ensured a disproportionate focus on herbivorous species. Indeed, in Sahul's case, large herbivores and invertivores tend

to be mammals (>95% and 100% of species in these trophic guilds, respectively; e.g., herbivores: kangaroos and wombats; invertivores: long-beaked echidna), whereas large carnivores are predominantly reptiles (≥79% of carnivores; e.g., crocodiles, goannas, and pythons), and large omnivores are birds (>62% of omnivores; e.g., emu *Dromaius novaehollandiae* and southern cassowary *Casuarius casuarius*). The non-random associations between taxonomic class and trophic guild in Sahul are striking, and raise other questions: Are similar patterns observed in large-animal assemblages on other continents? (If not, why not?) Do these patterns in species richness reflect differences in abundance, biomass and ecological 'importance'? and, Is there a physiological and/or an evolutionary reason why some classes are more prominent in certain trophic guilds? Irrespective of the answers to these questions, the non-random association between trophic guild and taxonomic class highlights the importance of considering a wide range of taxonomic diversity when assessing the ecological impacts of compositional changes in species assemblages.

We grouped species based on body size, taxonomic class, and trophic guild to identify overarching — but coarse-scale — shifts in community composition. However, unaccounted-for trait diversity within and among these pooled groups likely also influences species' functional roles, the selective pressures they face, and their responses to disturbances. For example, the >10 kg body-size threshold captured a wide range of body sizes (from 10 kg to >2,500 kg), and species at either end of this range could have been affected by changing conditions in different ways (Hilbers et al., 2016). Furthermore, we did not include traits associated with increased vulnerability identified in other study systems, such as habitat specialisation (Keinath et al., 2017). Future work linking compositional change in Sahul's communities to additional traits and finer-scale trait variation could help to identify the major mechanisms underlying these changes.

The composition of Sahul's large-bodied animal community has continued to shift since the Late Pleistocene, displaying clear changes in terms of richness and the proportion of species in different trophic and taxonomic groups. While all groups have been affected and continue to face threats today, native mammals and herbivores have declined the most. The reasons why mammals have been especially vulnerable in Sahul — and why taxonomic patterns of vulnerability and extinction differ from those observed globally — remain unclear. Irrespective of the causes of these non-random extinctions, the compositional shifts across taxa and trophic guilds in Sahul have altered the community's functional trait space and species interaction networks, which in turn has implications for community structure and function. Thus, the restructuring of large-animal communities in Sahul has broader implications for the persistence of ecological processes and the future survival or extinction risk of other species.

Supplementary materials for this research article can be found on the AQUA website https://aqua.org.au/qa-vol-42-no-1-si_llewelyn-et-al_supplementary-material.

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CABAH ART SERIES: CHANGING THE CONVERSATION

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HISTORY AND OBJECTIVES

The CABAH Art Series emerged from a bold and timely vision: to change the conversation about Australia's deep history. As a flagship component of the CABAH Education and Engagement (E&E) Program, the series was designed to reframe how Australians understand their ancient past and allow new audiences to engage with cutting-edge research. By integrating creative practice into deep time research, the Art Series sought to bring new voices into the discourse, bridge cultural and disciplinary divides, and create space for deeper reflection and dialogue.

Rather than positioning research communication as a one-way process, the Art Series embraced the principle of "two-way learning", inviting knowledge to flow between researchers and communities, artists and audiences, and Indigenous and Western ways of knowing. It recognized that meaningful engagement is not just about presenting facts but about co-creating meaning. The series aimed to elevate underrepresented perspectives, particularly those of Indigenous communities, and foster shared ownership of Australia's long and complex history. Ultimately, the Art Series helped build a foundation for public understanding rooted in connection, creativity, and mutual respect.

PROJECTS WITHIN THE SERIES

Spanning multiple years and disciplines, the Art Series commissioned a rich array of works—from immersive digital media and glass sculptures to performances and site-specific installations. Key projects include:

- **Where Lakes Once Had Water**
  A video and sound installation by Sonia Leber and David Chesworth, created through fieldwork with CABAH scientists in the Northern Territory. The work toured galleries nationally and invited audiences to imagine ancient landscapes through a sensory, speculative lens.
- **Unseeded**
  A series of 35 hand-blown glass boab nuts by artist UK Frederick, some of which are etched with the images the artist took on the fieldtrip in the Kimberley alongside researchers and Miriuwung Gajerrong Rangers. *Unseeded* was exhibited in Canberra and Wollongong.
- **Mangal Bungal**
  Meaning "clever with hands" in the Guugu Yimithirr language, *Mangal Bungal* was a three-day cultural festival led by the Dingaal people through the Walmbaar Aboriginal Corporation. Held at the Queensland Museum, the event brought Dingaal Country to life through dance, storytelling, workshops, and immersive digital projections, creating participatory experiences grounded in Country and community.
- **Ngurruwarra/Derndernyin – Stone Fish Traps of the Wellesley Islands**
  A panoramic 20m canvas co-created by ten Kaiadilt, Lardil, and Gangalidda artists celebrating fish traps, which are central to culture and identity of First Nations communities across the southern Gulf of Carpentaria. This collaboration between established and emerging artists from Mirndiyan Gununa Aboriginal Corporation and Mornington Island Art celebrated a long relationship with CABAH researchers, and was exhibited at NorthSite in Cairns and at Queensland Museum Kurilpa.

Alongside the Art Series, a number of other creative place-based projects enriched the reach and impact of CABAH research. *Wadgayinjang Nhay Nhaway* (We Still Make Them Today) showcased the resilience of cultural practices through workshops and exhibitions where community members demonstrated traditional techniques and artefact-making, emphasizing continuity and adaptation in the present. Artist Nola Taylor produced paintings reflecting her connection to the Lake Mungo story of CABAH's planetarium film *The Earth Above*. Meanwhile, at Wijingarra Butt Butt in the Kimberley, artist Warren Barunga created painted rock slabs that remain installed on Country—intended to be experienced in situ, the work preserves stories of the Arraluli clan and honours cultural sovereignty by embedding art in its ancestral landscape.

Figure 1: Sonia Leber and David Chesworth, *Where Lakes Once Had Water* (video stills), 2020, 2-channel 4K UHD video, stereo audio, 28:24 minutes. University of Wollongong Art Collection. CABAH Art Series Commission in association with Bundanon. Filmed on the lands and waters of the Mudburra, Marlinja, Jingili, Elliot, Jawoyn and Larrakia communities in Northern Territory, Australia, with additional filming and editing on Barkandji, Dharawal, Djabugay, Yidinji and Wurundjeri Country.

Opposite Page – Figure 2: Detail from *Unseeded*: (above) illustrating how the glass form casts a shadow image of Professor Jane Balme looking for archaeology, and (below) showing three of the 35 glass forms. (Photo credit: UK Frederick).

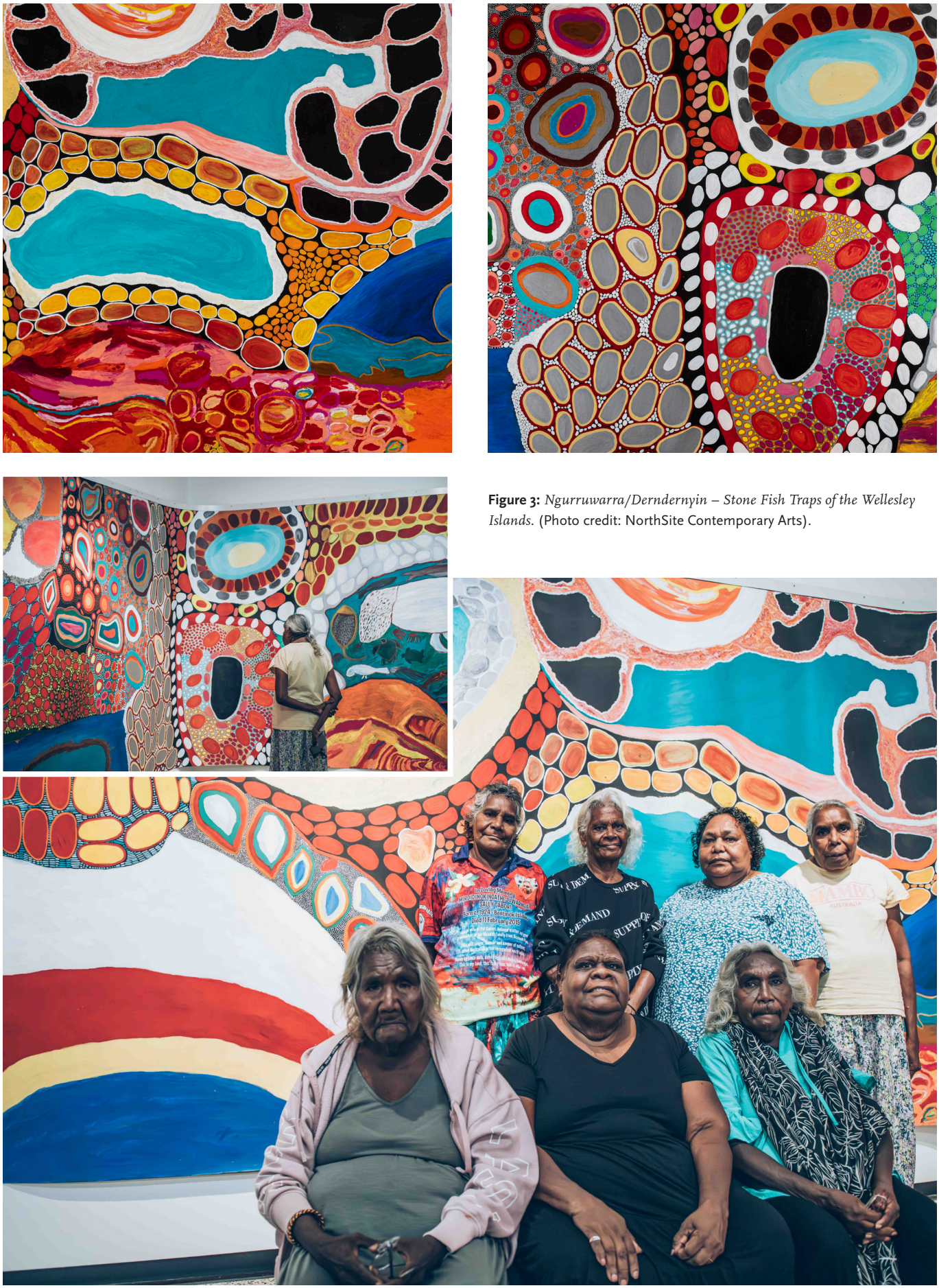

Figure 3: *Ngurruwarra/Derndernyin – Stone Fish Traps of the Wellesley Islands.* (Photo credit: NorthSite Contemporary Arts).

EVALUATING THE ART SERIES

From the outset, CABAH wanted to ensure the impact and learnings from the E&E program, and specifically the Art Series, were measurable and communicable beyond the project outputs themselves. The evaluation of the Art Series, led by Chief Investigator Lizzie Muller (UNSW), was designed to align with CABAH's broader impact vision—specifically its goal of "changing the conversation" about Australia's deep history. The evaluation took a generative and responsive approach, aiming to understand how the artworks fostered shifts in voice, context, perspective, and action. Guided by a model of two-way learning, the process assessed how different artworks brought new voices into the conversation, altered the settings and modes of engagement, influenced how people think about Australia's past, and inspired new possibilities for action. This emergent and dialogic method reflected contemporary international standards for evaluating research impact and emphasized inclusive, multi-perspective storytelling as central to research engagement.

MAJOR OUTCOMES AND IMPACT

The detailed evaluation shows the Art Series has had a profound and lasting influence, becoming a powerful mechanism for amplifying Indigenous voices in national conversations about heritage, culture, and Country. Through events like *Mangal Bungal*, the series demonstrated how cultural festivals and community-led storytelling can create deeply personal and immersive encounters with Country. By presenting research through creative formats that engage the senses and the emotions, the series succeeded in reaching new and diverse audiences across Australia.

The process also impacted the research community itself, encouraging scientists to reflect on their own methodologies and to explore more inclusive and collaborative approaches. Artists were not just interpreters but co-creators, shaping the questions, methods, and stories that emerged. As a result, the Art Series not only showcased interdisciplinary excellence but also became an example of how partnerships between science, humanities, and Indigenous knowledges can produce culturally rich and socially resonant work.

HOW THE SERIES HAS CHANGED THE CONVERSATION IN AUSTRALIA

The CABAH Art Series has played a pivotal role in reshaping public discourse about Australia's deep history. It shifted the focus from ancient artefacts and distant timelines to living relationships between people, place, and knowledge. The artworks brought that shift into public space—placing Country, culture, and community at the heart of immersive and interactive experiences.

This change was not only thematic but structural. The Series changed who gets to speak, where those conversations happen, and how they unfold. Indigenous artists and communities were positioned not as subjects but as collaborators and narrators. Conversations occurred not only in academic journals or museums, but on Country, in public forums, and through creative media. The result was a broader, more inclusive dialogue that acknowledged the complexity and plurality of Australia's past.

As the Series concludes, its legacy continues in the stories it sparked, the relationships it fostered, and the models it offers for future collaborations. The conversation has changed—and through continued care, listening, and innovation, it will continue to evolve.

TRAPS 'N' MAPS: DEVELOPING A PALYNOLOGICAL MONITORING NETWORK ACROSS AUSTRALIA

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Understanding how pollen moves from ecosystems to fossil deposits is key to reconstructing Australia's environmental past. Traditionally, moss cushions have been used to study pollen accumulation. However, in many Australian landscapes, moss is sparse, and so an alternative is needed. Artificial pollen traps can fill this gap, and so, with the support of an internal CABAH grant, we created Traps 'n' Maps (TnM) to help document annual pollen deposition and associated plant cover as far and as wide as possible. It's a monumental task, though; too vast for any single research team to tackle alone. Which is why we also created VegeMap, a supporting citizen science project designed to build a network of helpers and extend our capabilities.

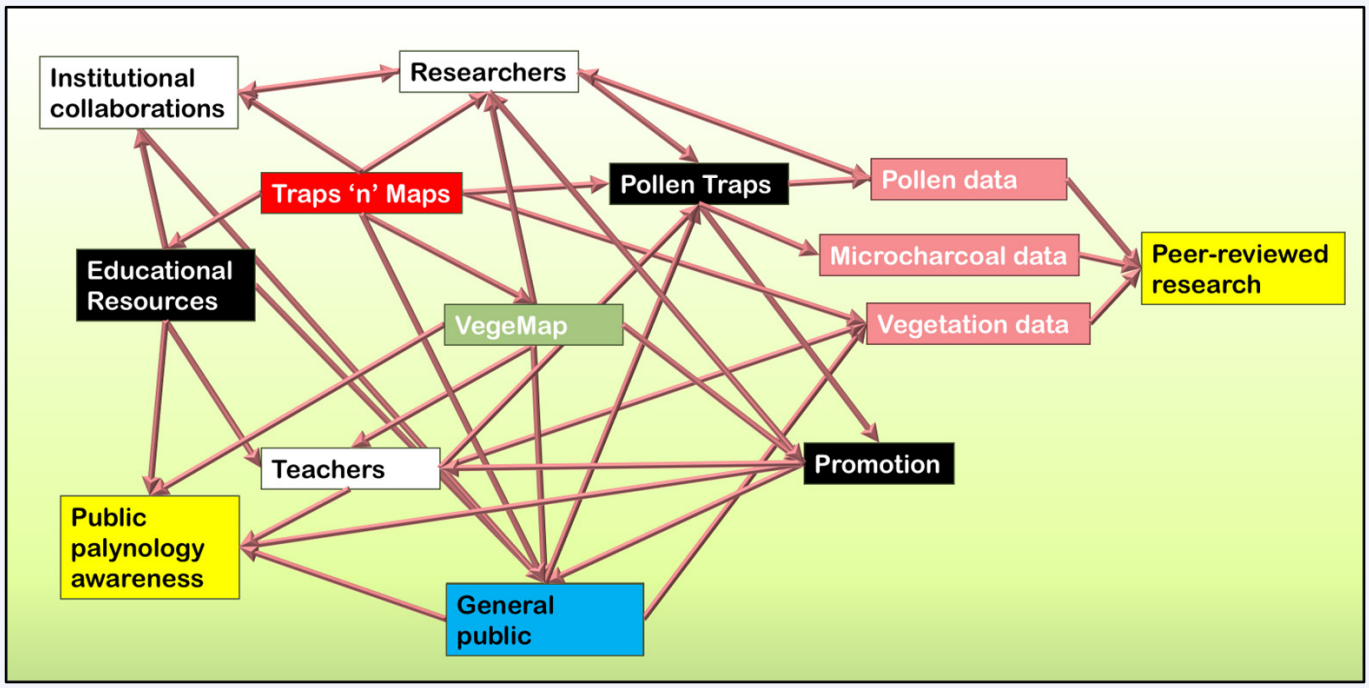
BACKGROUND: WHY TRAP POLLEN?

The journey from a living ecosystem to a fossil pollen assemblage passes through many filters. Modern palynology often strives to capture absolute values of pollen accumulation rates (PARs), allowing an understanding of pollen abundance not possible in proportional estimates. Pollen production estimates (PPEs) of modern vegetation continue to resolve the connection between preserved pollen abundance and vegetative cover. PPEs are unique to regions and ecosystem types and require painstaking fieldwork and modelling. In Australia, this work has been pioneered by Mariani et al. (2016, 2022), laying a foundation for tailor-made PPEs for Australia's southeast (see Wills et al., this issue).

Work constructing PPEs often uses moss cushions as natural pollen archives. In the large areas of Australia where moss growth is restricted or absent, however, artificial pollen traps can fill the gap. Furthermore, pollen traps can be constrained to collect pollen for precise amounts of time, while moss cushions cannot. CABAH's internal grant scheme provided an invaluable opportunity to set up a network of annually collected pollen traps. The Traps 'n' Maps project has set pollen traps across the continent with accompanying vegetation surveys (maps). The project also aims to add a new dimension to palynology in Australia by adding the estimation of local biomass to vegetation surveys around traps. This is an important step in understanding the connection between PPEs and the density of vegetative coverage and tree size.

Studies across the globe, increasingly including understudied regions like Australia, have demonstrated the power of models like REVEALS (that reconstruct quantitatively regional vegetation abundance) coupled with PPE calibration to yield meaningful estimates of vegetation cover (Blarquez & Aleman, 2016; Serge et al., 2023; Schild et al., 2024; Mariani et al., 2024). The potential to further translate PPEs into biomass and carbon stock estimates is also being actively explored (Abraham et al., 2020; Knight et al., 2022). Quantitative pollen-derived histories have the potential to provide context for understanding long-term ecosystem change, testing Earth system model simulations, and guiding conservation by revealing the range of natural variability and human impacts in these ecosystems. With ongoing research, like Taps 'n' Maps, we can expect further convergence on robust techniques that make fossil pollen an increasingly powerful quantitative record of past vegetation cover and biomass in Australia.

Concerted annual pollen monitoring can also provide data for other applications. Pollen traps capture microcharcoal. Monitoring the production and distribution of charcoal by bushfires in the modern era could lead to improvements in our interpretation of fossil microcharcoal. Pollen monitoring will also provide phenological data for the monitored year, allowing insight into what plants have and have not flowered. The traps capture any windblown particles above ~3 μm; in principle, studies of any components of aeolian dust—minerals, microplastics, salts—could be explored.



Key	NVIS Major Veg. Group	Trap
	Rainforests and Vine Thickets	TRUE
	Eucalypt Tall Open Forests	TRUE
	Eucalypt Open Forests	TRUE
	Eucalypt Low Open Forests	TRUE
	Eucalypt Woodlands	TRUE
	Acacia Forests and Woodlands	FALSE
	Callitris Forests and Woodlands	FALSE
	Casuarina Forests and Woodlands	TRUE
	Melaleuca Forests and Woodlands	TRUE
	Other Forests and Woodlands	FALSE
	Eucalypt Open Woodlands	TRUE
	Tropical Eucalypt Woodlands/Grasslands	TRUE
	Acacia Open Woodlands	TRUE
	Mallee Woodlands and Shrublands	TRUE
	Low Closed Forests and Tall Closed Shrublands	FALSE
	Acacia Shrublands	TRUE
	Other Shrublands	FALSE
	Heathlands	FALSE
	Tussock Grasslands	TRUE
	Hummock Grasslands	TRUE
	Other Grasslands, Herblds, Sedgelds, Rushlds	FALSE
	Chenopod Shrublands, Samphire Shrub, Forblds	TRUE
	Mangroves	FALSE
	Inland Aquatic - freshwater, salt lakes, lagoons	FALSE
	Cleared, Non-Native Vegetation, Buildings	TRUE
	Unclassified Native Vegetation	FALSE
	Naturally Bare - sand, rock, claypan, mudflat	FALSE
	Sea and Estuaries	FALSE
	Regrowth, Modified Native Vegetation	TRUE
	Unclassified Forest	FALSE
	Other Open Woodlands	FALSE
	Mallee Open Woodlands, Sparse Mallee Shrub	TRUE
	Unknown/No Data	FALSE

Figure 1: A conceptualised network of the activities and stakeholders involved in TnM.

PROJECT DESIGN

A major aspect of the Traps 'n' Maps project is direct fieldwork—setting up transects of pollen traps and vegetation survey sites along rainfall gradients. Many factors are considered for site selection, and so far, three transects have been prioritised for the team's annual campaign (Figure 2).—the Daintree Rainforest to Chillagoe in Far North Queensland, from Darwin to South Ghan in the Northern Territory, and from Canberra to the Strzelecki Desert. These transects are designed to capture the diversity of Australia's ecosystems, regions, and rainfall amounts. Seventeen vegetation types, including some of the wettest and driest in Australia, were also targeted based on National Vegetation Information System (NVIS) maps (NVIS Technical Working Group, 2017).

Overall, pollen traps are currently maintained in NSW, ACT, VIC, QLD, SA, NT, and the Bass Strait Islands, with many in state and national parks and forests. Plans are underway to expand the network to include sites in WA and mainland Tasmania.

Many sites align with key Terrestrial Ecosystem Research Network (TERN) monitoring sites to leverage their extensive, detailed vegetation surveys. Traps have also been placed adjacent to Canberra Pollen's daily pollen counter, the Australian National Botanic Garden, and the Olive Pink Botanic Garden in Alice Springs.

Finally, TnM has also chosen sites along a foundational pollen trap transect developed and maintained by the pioneering palynologist, Gurdip Singh, in the 1970s and 1980s. The TnM transect from Canberra to the Strzelecki Desert replicates many of Singh's sites. Much of the data produced by that ambitious project has remained unpublished since Singh's unexpected passing in 1991. Thankfully, his data has been stewarded by Prof Emeritus Peter Minchin. He, Prof Emeritus Jari Oksanen, and the TnM team are progressing towards publishing that data and demonstrating its potential for reconstructing environmental conditions. By replicating Singh's pollen traps, TnM hopes to build on his groundbreaking dataset.

VEGEMAP

The other major aspect of TnM is VegeMap, which is centred around citizen science, relying on volunteers to install pollen traps and conduct vegetation surveys.

VegeMap aims to extend TnM's data collection as well as spread knowledge about palynology. Building, installing, and collecting pollen traps, and vegetation surveys, requires a commitment in time and effort, so VegeMap has been designed to target participants who might have more buy-in, such as teachers and non-palynologist researchers. We refer to these participants as "artisan scientists", as they also tend to have more expertise than a typical citizen scientist. Much of the work done by the TnM team has focused on developing the infrastructure for this citizen science scheme, as detailed in the following sections.

To increase capacity for placing traps and conducting vegetation surveys, citizen science has always been a key part of the project. Design of simple, cheap, and easy-to-build pollen traps was essential to facilitate non-scientist participation, which necessitated novel processing methods in the laboratory. Production of a suite of educational resources incentivises citizen scientists to participate. Collaborations with other researchers and institutions have led to further expansion of the project (Figure 1).

TRAP DEVELOPMENT

VegeMap requires a simple, cheap, and reproducible pollen trap construction. The design follows a long line of pollen traps from Tauber (1973), Bush (1991), and Gosling et al. (2002). The traps are, in the words of Tauber (1973), "static and non-overload", meaning they have no moving parts and can accumulate a year's (or many years') worth of pollen without becoming overloaded, as slide-based trap designs do. In essence, the design used by VegeMap is a funnel with a filter inside that will collect any wind- or rain-borne particles, while allowing water to drain through (Figure 3).

The exterior of the trap consists of a 14 cm PVC funnel enclosed in 1.2 mm fibreglass flyscreen mesh, held in place with a hose clamp around the bottom. Inside the funnel, at the base of the cup, a smaller piece of flyscreen is taped to prevent insects and other critters from crawling in from below, creating an inner chamber that will allow in airborne particles but excluding anything larger than 1.2 mm. A filter was placed on top of the small, inner piece of mesh, allowing rainwater to drain out, but capturing pollen-sized particles. Finally, on top of the filter, a flocculent medium was added to entangle particles to facilitate their capture and approximate the texture of moss cushions, making the data produced more comparable to other studies of modern pollen. Several materials were explored for the filter and inner medium.

To estimate PAR, pollen recovery must be able to be estimated, i.e. the amount of pollen recovered from the trap must be known. Initially, glass fibre filters were used and dissolved in hydrofluoric acid (HF), allowing, in principle, for 100% recovery of palynomorphs from the filter. HF is, however, extremely hazardous and the risks and time requirements make its use impractical and unsafe to scale up. The interior medium was cotton. None of the chemicals used in standard pollen preparation procedures (Faegri & Iversen, 1989) nor digestion by the enzyme cellulase successfully broke down cotton fibers. Pollen was difficult to count and identify in slides due to the presence of abundant cotton fibers.

In a second design, glass fibre filters were replaced with cellulose acetate filters and the cotton with cigarette filters, also made of cellulose acetate. These readily dissolve in dichloromethane (DCM). Unfortunately, DCM is approximately the same density of pollen, 1.3 g/mL, making concentration by centrifugation impossible. Dilution with acetone, ethanol, and water immediately resulted in the precipitation of cellulose acetate, as did evaporation of DCM, recapturing any pollen.

Finally, a workaround was developed. Borrowing from standard pollen preparation, we added a tablet of pre-counted *Lycopodium* spores directly to the trap on installation. This spike allows us to estimate the amount of palynomorphs lost in the sample recovery procedure, as well as during preparation.

VEGETATION SURVEYS

Our current vegetation survey protocol strikes a balance between efficiency and thoroughness. Five metre by five metre quadrats are set up around the trap. Quadrats are broken up into ground, midstorey, and overstorey layers. The most abundant plants are described and identified as specifically as possible. Participants are encouraged to use the iNaturalist app and community resources to improve identification. Visual estimation charts are used

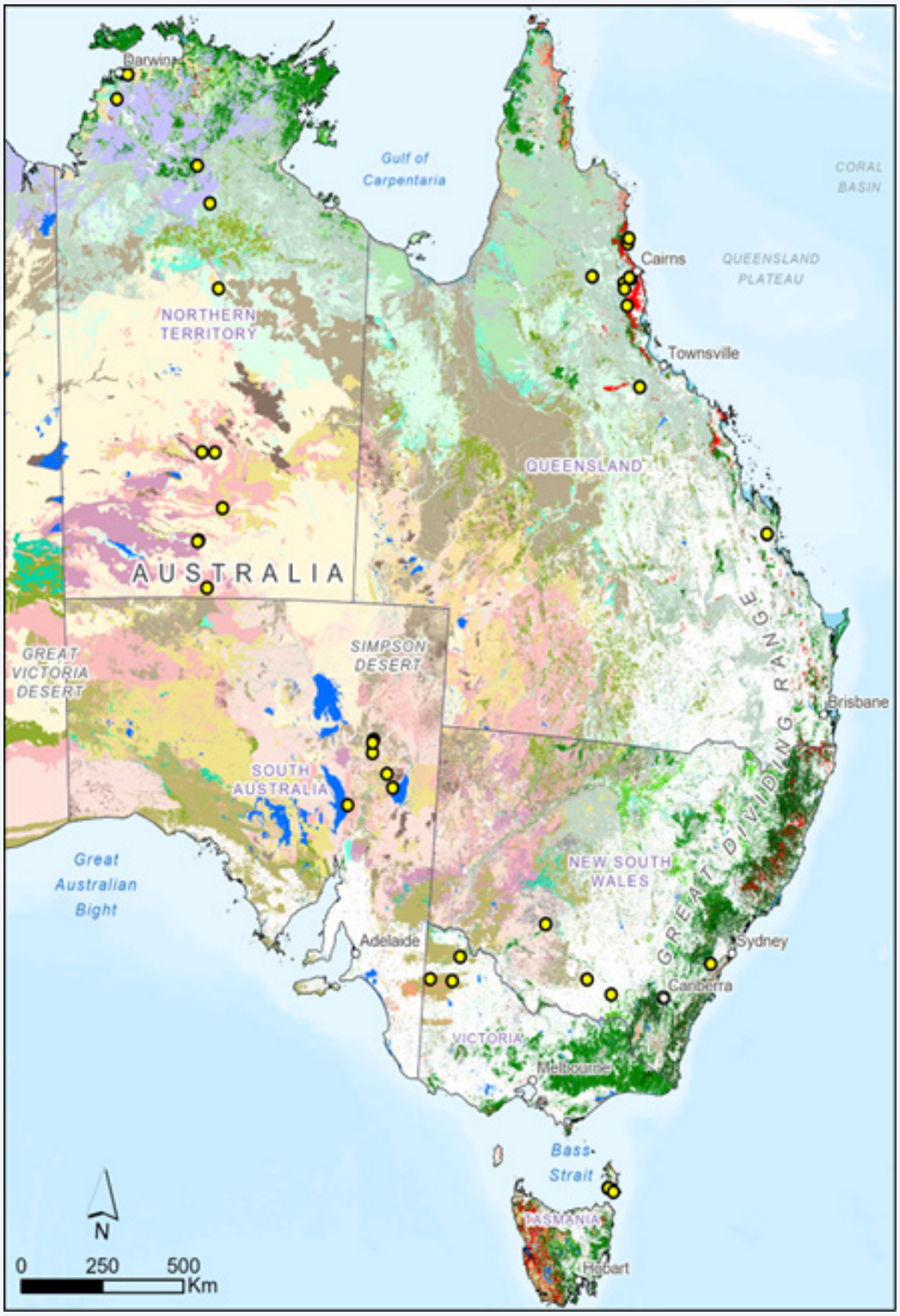


Figure 2: Map of VegeMap pollen traps (yellow dots) and NVIS land cover.

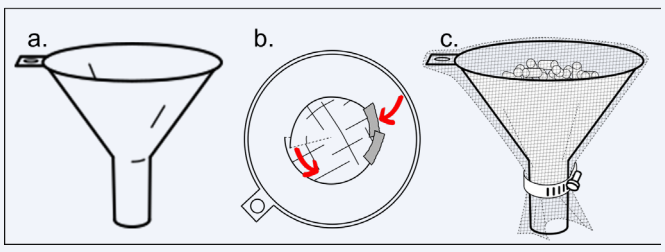


Figure 3: Diagram of pollen trap design. **A)** Inside the funnel; **B)** A portion of flyscreen is taped to the bottom, then a filter on top of that. Then a medium (cotton in early designs, cigarette filters in the current design) is added; **C)** Finally, the trap is wrapped in flyscreen, held in place with a hose clamp.

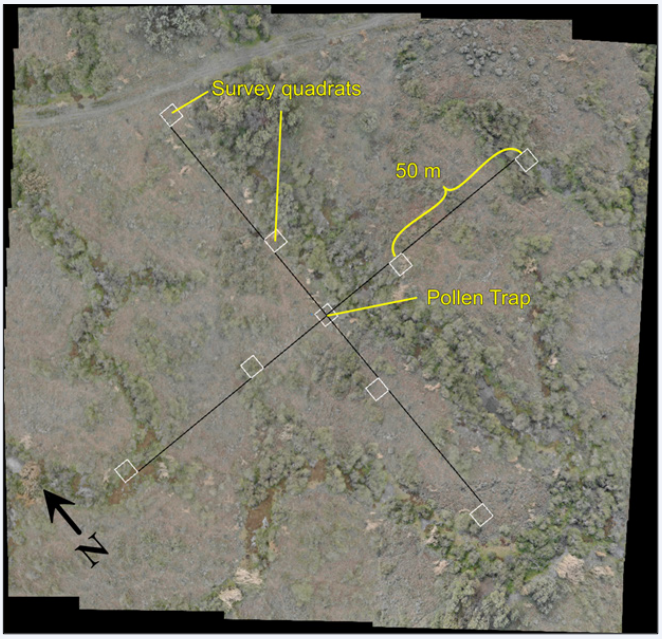


Figure 4: Arrangement of 5 x 5 m vegetation surveys relative to the pollen trap. One at the trap, two in each cardinal direction at 25, then 75 m from the trap.

to estimate coverage of each species in each layer. Finally, any trees with trunks over 10 cm diameter at breast height are measured. Participants are encouraged to do surveys immediately around the pollen trap, at 25 m distance in each cardinal direction from the trap, and at 75 m in each cardinal direction from the trap (Figure 4), but reminded that putting up a pollen trap with little or even no vegetation surveying is still a valuable contribution.

LOGISTICS

When someone expresses interest in participating in VegeMap, they are sent a cellulose acetate filter, a *Lycopodium* tablet, and a QR coded tag made of durable Tyvek. They also receive instructions detailing 1) trap construction, 2) trap installation, 3) surveying vegetation, and 4) trap collection and return (Figure 5). Participants are asked to contribute the other components of the trap and required equipment, which are detailed in the instructional material. Participants are directed to a Google Form where they are prompted to provide details about the placement of their trap(s) and vegetation surveys.

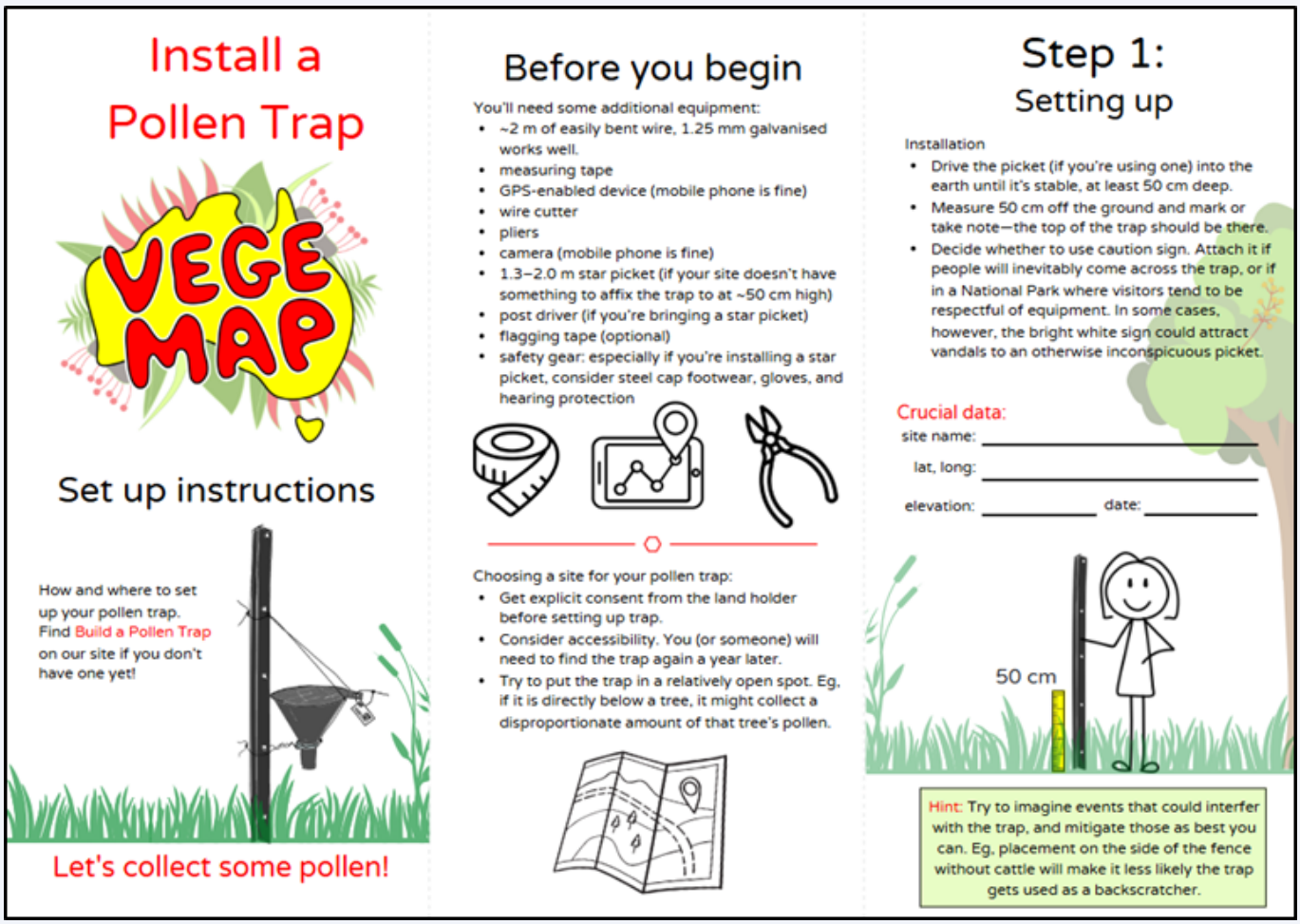


Figure 5: Example instructions for VegeMap participants.

APPEALING TO PARTICIPANTS

To attract teachers, VegeMap has been producing classroom-friendly activities using pollen as a focus. TnM researchers have visited primary and secondary schools to test and develop these activities with students (Figure 6). Material is organised by grade level and learning area; curriculum requirements that may be related to topics covered in VegeMap activities are also flagged. Background information on topics like plant reproduction, deep history, and light microscopy is provided and flagged for related curriculum requirements.

Ideally, VegeMap will provide teachers with a resource to make teaching easier and more fun. It will also raise public knowledge of palynology, which, despite being a pillar of palaeoecology, is virtually unknown to general audiences. But the *raison d'être* of VegeMap classroom materials is to integrate the activities with placing a pollen trap and doing vegetation surveys with students.

VegeMap is also targeting non-palynologist experts by offering low-effort and low-cost data collection. For about $20 and a few hours of work, researchers can add pollen data to their project. For example, Capricorn Caves in QLD have integrated VegeMap pollen traps into their cave monitoring program (Figure 7). The managers of Capricorn Caves carefully monitor the humidity, temperature, airflow, and hydrology inside the caverns. They decided that adding pollen traps to their monitoring equipment was a low-effort way to add a new dimension to their understanding of the environments in their caves. Traps have been placed inside caves that hold public tours, caves that are closed to the public, and in the woodland surrounding the cave entrances. Analysis of these could shed light on the transport of pollen into caves, particularly allowing comparison between instances when humans are or are not vectors. This data has the potential to illuminate the transport of pollen into caves in archaeological contexts.

CONCLUSION

TnM is laying a strong foundation for a new era of palynological research in Australia. It is establishing the first continent-wide network of pollen traps, linking modern pollen rain to the surrounding vegetation and biomass across a diverse range of Australian ecosystems. TnM is now entering the third year since its inception. 2024 was the first-year pollen traps were collected and samples from 52 sites are currently being processed and analysed at the Australian National University. As of this writing, 18 trap kits have been sent out in 2025 to be installed at new sites. As a point of comparison, the European Pollen Monitoring Programme began in 1996 and included 351 trap locations 24 years later in 2020 (Abraham et al., 2020).

Figure 6: Alex F Wall playing the board game Pollenscape (developed by Janelle Stevenson) with students at Chillagoe State School while on the Far North Queensland field campaign. (Photo credit: Giselle Owens).

Figure 7: VegeMap pollen trap in Bellfrey Cave, at Capricorn Caves, Queensland. (Photo credit: Erin Greatbatch).

By combining researcher-led transects spanning from tropical rainforests to arid interior deserts with a broad citizen science network, TnM is collecting robust data on annual pollen deposition and corresponding plant cover. VegeMap's "artisan science" approach expands the reach of data collection while engaging the public in ecological monitoring, allowing participants to contribute to a richer understanding of Australia's environments, present and past. The project has produced innovations in the field, including a simple, low-cost pollen trap design and a survey protocol that allow volunteers and school groups to participate without specialised equipment. These efforts are already yielding a novel dataset that will be invaluable in interpreting fossil pollen records. As the network of pollen traps expands and more years of data accumulate, the project will become increasingly valuable. Early accomplishments of TnM underscore the importance of interdisciplinary and multi-institutional organisations like CABAH. Such comprehensive monitoring and mapping of vegetation through pollen has not been undertaken in Australia before, and its success will leave an enduring mark on how we interpret the story of Australia's unique ecosystems.

ACKNOWLEDGEMENTS

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USE OF ARTIFICIAL INTELLIGENCE STATEMENT:

During the preparation of this work the authors used ChatGPT-4o for proofreading and to improve clarity. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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POLLEN MODELLING TO QUANTIFY AUSTRALIA'S CHANGING VEGETATION: A DECADE OF PROGRESS

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A DECADE OF POLLEN MODELLING IN AUSTRALIA

It is a special year for Australian Palynology, marking 10 years since the first fieldwork activities were undertaken to calibrate modern pollen-vegetation relationships in southeastern Australia. Because different plants produce different amounts of pollen, this modern calibration is required to achieve more realistic reconstructions of past vegetation (Sugita, 2007a, 2007b) REVEALS, that estimates regional vegetation composition using pollen from 'large lakes' that have small site-to-site variations of pollen assemblages even if vegetation is highly heterogeneous. Once these data have been used to quantify regional vegetation composition within 10\n 4\n -10\n 5\n km\n 2\n , background pollen, one of the parameters crucial for vegetation reconstruction, can be estimated for smaller-sized sites, and incorporated into the Landscape Reconstruction Algorithm (LRA. Field-based data are integrated into pollen dispersal models to obtain the key parameters needed to convert pollen counts into land cover percentages: Pollen Productivity Estimates (PPEs).

The roots of this kind of research go much deeper. Many researchers in Australia have explored the pollen–plant relationship, using surface samples, often pollen traps or moss cushions (e.g., Kershaw, 1973; Kershaw & Hyland, 1975; Ladd, 1979; Kershaw & Strickland, 1990; Fletcher & Thomas, 2007) which show great variation with respect to altitude, rainfall and soil parent material, surrounded by a great expanse of open eucalypt woodland. In order to attempt to explain this vegetation pattern it was decided to undertake a study of one rain-forested area. The Atherton Tableland was selected as it contains a number of volcanic craters with accumulated organic sediments suitable for pollen analytical investigation and it lies within a topographically and climatologically diverse area where the presence of a variety of rain-forest types and eucalypt woodland suggested that any past changes would be clearly indicated in pollen records. To assist in the interpretation of results from pollen analysis of sediment cores, stratigraphic and aquatic vegetation investigations of the crater sites were undertaken (Chapter 3, surface samples from lakes or mires (e.g., Kershaw, 1970, 1979; Hope, 1974; D'Costa & Kershaw, 1997) or pollen accumulation rates (Walker, 2000). Their work showed how pollen production differed between species, but also between ecosystems. Tropical rainforests, for example, produce very little pollen that is poorly dispersed, while Casuarinaceae-dominated woodlands tend to produce far more pollen per area than other ecosystems. These observations allowed generations of palaeoecologists to fine-tune their interpretations – for example, in the application of biome level vegetation reconstructions (Pickett et al., 2004) – prior to the development of quantitative PPEs.

In the context of Australia, the first set of PPEs was estimated in western Tasmania in 2016 (Mariani et al., 2016). This progress builds upon a century of pollen modelling theory, right from the inception of Quaternary palynology as a discipline in 1916 by Lennart von Post (Edwards et al., 2017; Birks & Berglund, 2018). This realisation led to the Iversen's (1947) 'Correction Factors', then Davis' (1963) R-value, applied by Andersen (1970), culminating in the Extended R-value (ERV) approach to correct pollen production and dispersal biases as PPEs, incorporating local and background pollen influences of the pollen counted from a record (Parsons & Prentice, 1981; Prentice & Parsons, 1983; Sugita, 1994). Building upon this legacy, we applied this theory to Australia, the first region in the southern hemisphere to develop PPEs.

To estimate pollen productivity for different plant taxa, we collect samples from moss cushions (which trap pollen from recent years; Pardoe, 1996; Pardoe et al., 2010). We also survey the vegetation at various distances around the sampling site (Bunting et al., 2013) and combine these field observations with regional vegetation data (The Digital Vegetation Map of Tasmania (TASVEG) and the Modelled Ecological Vegetation Classes 2005 (EVCs)). Dispersal models are used to weight the vegetation so that it can be compared to the pollen composition of the samples (Theuerkauf et al., 2013). PPEs are the result of this calibration. Because of the requirement for multiple

samples for each plant taxon, PPEs have been estimated for pollen types that are well represented in both plant surveys and pollen assemblages (Mariani & Connor, 2019). The mismatch between plant cover percentage and pollen percentage is evident for Australian mid-storey species like *Proteaceae, myrtaceous* shrubs and *Acacia* (low pollen producers/dispersers), which results in their underestimation in the pollen records (Mariani et al., 2022). A surprise was the relatively low pollen production of *Poaceae* (0.12 –0.41) and the relatively high pollen production of *Eucalyptus* (Table 1).

The current set of PPEs for southeastern Australia (from Victoria and Tasmania; Mariani et al., 2022) has paved the way for a comprehensive understanding of past vegetation changes, the role human agency has on vegetation cover, and the creation of Australia's current "tinderbox" forests susceptible to catastrophic wildfires. We are thankful to CABAH for their support to MM, HC and SC through the past several years, for funding fieldwork and promoting our work. This work on PPEs will also serve as a direct comparison, in several regions, to CABAH's long-term Traps 'n' Maps project (see this issue), which has deployed purpose-built pollen traps across different regions of Australia to create a broader set of PPEs. In this short report, we will reflect on what we have already achieved using pollen modelling techniques and what pollen modelling milestones still lie ahead.

UNVEILING ANCIENT CULTURAL LANDSCAPES

In 2017, we applied pollen modelling techniques for the first time in the Southern Hemisphere using the Regional Estimates of VEgetation Abundance from Large Sites (REVEALS) model (Sugita, 2007a), confirming Tasmania's "wilderness" as an ancient cultural landscape where cultural burning controlled forest encroachment over thousands of years. The research also proved that pollen modelling can be applied to environments dominated by animal pollination rather than purely wind pollination (Mariani et al., 2016, 2017). Subsequently, in 2022, we identified structural vegetation changes that occurred after European colonisation (1788 CE) with the loss of Indigenous cultural burning activities. Driven by colonialism, southeastern Australia's woodlands became a highly flammable environment. This legacy persists today and contributes to events like the catastrophic "Black Summer" fire season of 2019/20. Our reconstructions show the stark contrast between pre-colonial landscapes (with woodland openness maintained by widespread cultural burning activities) and today's bushfire-prone conditions promoted by colonial land-use change and 20th-century management techniques such as fire suppression (Mariani et al., 2022).

Table 1. Relative PPEs for Australian taxa, ordered from the highest pollen producers to the lowest. Area categories are: TAS = Tasmania, AUM = Australian mainland, and REF = reference taxon (all PPEs are relative to this taxon). Taxa with an asterisk (*) have PPEs for both study areas. A rough estimate of regional plant cover can be obtained by dividing pollen counts from the region by these PPEs prior to calculating percentages. Refer to Mariani et al. (2022; Table S3).

TAXON	REL. PPE	AREA
Casuarinaceae	1.35	AUM
Athrotaxis-type	1.34	TAS
Nothofagus cunninghamii	1.28	TAS
Eucalyptus	1.00	REF
Phyllocladus asplenifolius	0.84	TAS
Asteraceae	0.62	AUM
Callitris-type	0.59	AUM
Monotoca	0.48	TAS
Poaceae*	0.41	TAS
Nothofagus gunnii	0.39	TAS
Eucryphia lucida	0.34	TAS
Sprengelia	0.21	TAS
*Leptospermum**	0.15	TAS
Melaleuca	0.14	AUM
Poaceae*	0.12	AUM
Banksia	0.09	AUM
Bauera	0.07	TAS
Ericaceae	0.07	TAS
*Leptospermum**	0.06	AUM
Gymnoschoenus sphaero.	0.05	TAS
Acacia	0.03	AUM

EXTENDING THE TIMELINE

In 2023, with CABAH's support, we spread our sampling sites to cover more of southeastern Australia and expanded our timeline. These results were presented in four key phases of human occupation: (i) no human activity during the Last Interglacial, also known as Marine Isotope Stage (MIS) 5e, 130 to 115 thousand years ago (ka), (ii) relatively low human activity in early to mid-Holocene, ending at 6 ka, (iii) intensified human activity in the mid-to-late Holocene, 6 to 1 ka, and (iv) postcolonial cultural burning suppression from ~1788 CE. Our results indicated that human agency became a critical driver of vegetation cover in southeastern Australia during the mid-late Holocene. Cultural burning practices helped reduce shrub cover by 50% to its lowest recorded level (Mariani et al., 2024; Figure 2)creating high-intensity fires. Our research provides a deep-time perspective on shrub fuel loads in fire-prone southeastern Australia. Comparing 2833 records for vegetation cover, past climate, biomass burning, and human population size across different phases of human occupation, we demonstrated that Indigenous population expansion and cultural fire use resulted in a 50% reduction in shrub cover, from approximately 30% from the early to mid-Holocene (12 to 6 thousand years ago. The implication is that southeast Australia is a bio-cultural landscape that relies on traditional practices like cultural burning for proper ecological functioning.

WHAT'S NEXT?

Reflecting on a decade of pollen modelling advancements in Australia, the next ten years present exciting opportunities for expanding our spatiotemporal understanding of past landscapes, pre-colonial Caring for Country activities, fire histories, and the human-climate agency interface of Australia's ancient cultural environments. Our future research aims to fill key global and Australian gaps on past variability of fuels for fires and the landscape-scale legacies of past human practices (Indigenous and colonial), building upon our pollen-vegetation calibration, past land-cover, fire history and biomass reconstructions. Some new projects to look out for are:

1) Pollen productivity estimates under changing climates

We have been building new Australian PPE sets along a moisture-temperature gradient, aiming to refine our understanding of how PPEs vary under different climate scenarios. Recent fieldwork in 2023 and 2024 sampled new moss cushions and surveyed vegetation in several regions, including the dry inland areas of Victoria. This in-progress research represents an attempt to create PPEs applicable to the Last Glacial Period (LGP) (11.7-115 ka). This work will be complemented by the data collection in CABAH's Traps 'n' Maps project.

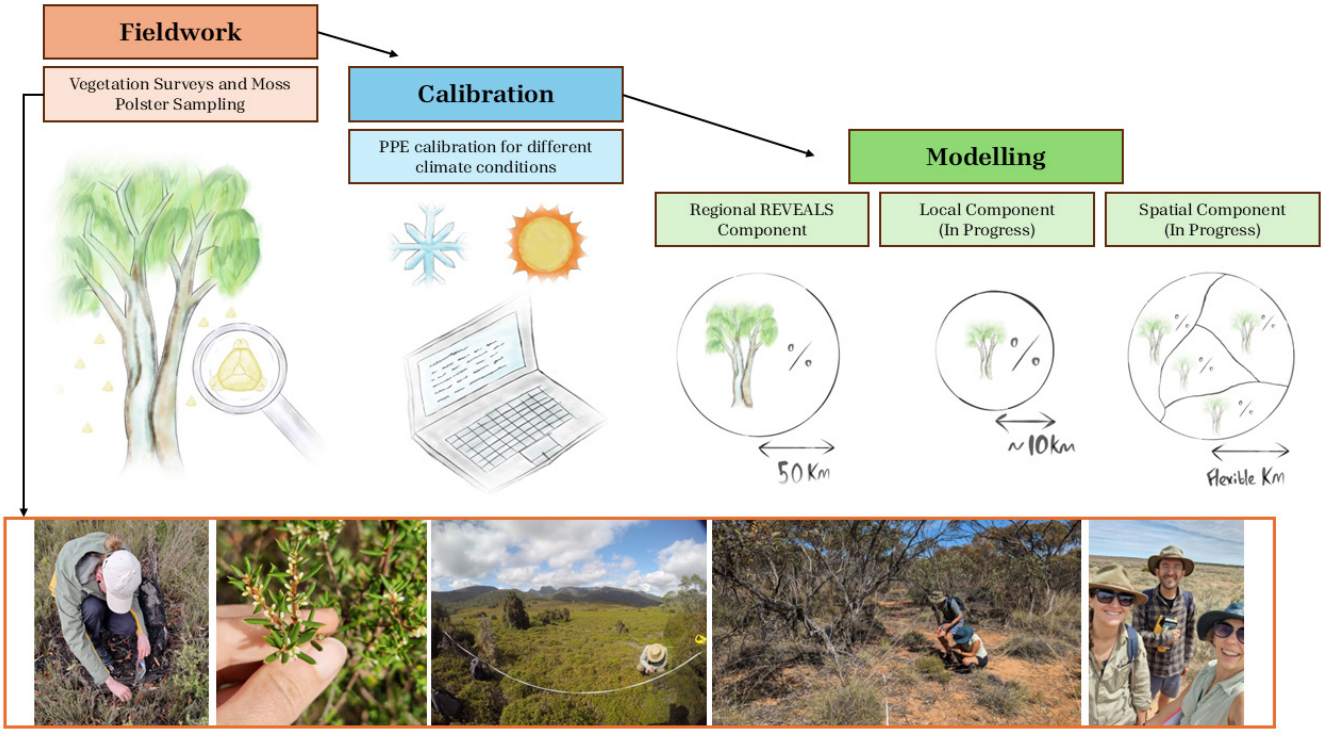

Figure 1: Workflow used for pollen modelling applications in Australia and fieldwork photos taken during expeditions from cool wet Tasmania to semi-arid inland Victoria (2015-2024). The results from the Fieldwork and Calibration steps were published in Mariani et al. (2016, 2017, 2022). The Regional REVEALS Component was published in Mariani et al. (2017, 2022, 2024).

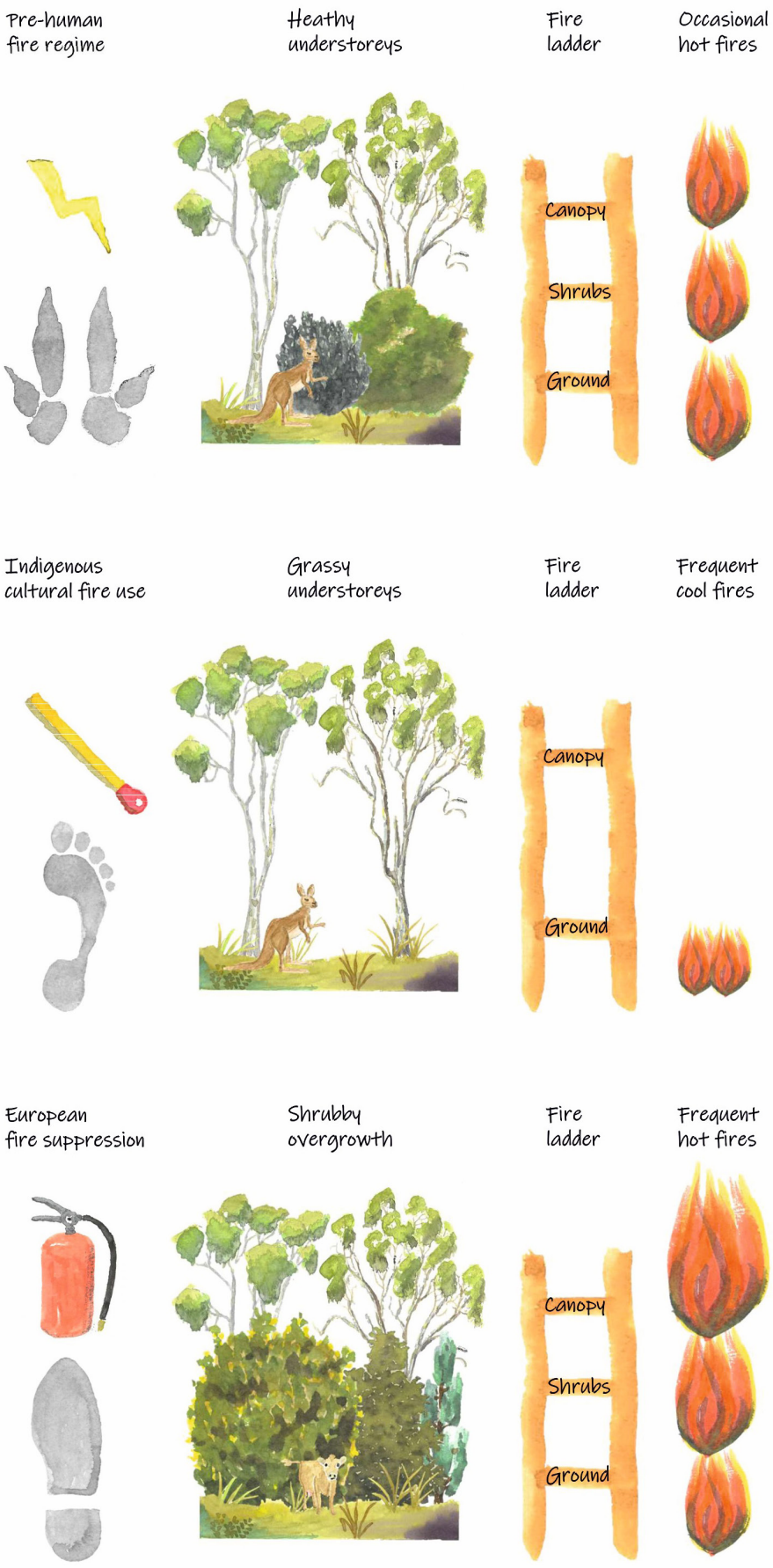

Figure 2: Summary timeline of past landscape changes across southeastern Australia, from pre-human contact (top), through Indigenous population expansion (middle), to the present (post-colonial, bottom). (Photo credit: Simon Connor).

2) Local-scale pollen modelling techniques

While large-scale vegetation patterns (50km from a single pollen record) remain a central focus of ancient vegetation modelling, we have yet to apply modelling approaches suited for smaller scales (≤10km radius a pollen record), capturing localised environmental changes and cultural management practices.

3) Maps of ancient vegetation cover from pollen

Recent developments in the European sphere of palynology have brought forward the creation of spatially meaningful quantitative vegetation reconstruction models like the Extended Downscaling Approach (EDA) (Theuerkauf & Couwenberg, 2017). While these techniques have been validated and applied to Holocene (11.7 ka – present) pollen records in Europe, no equivalent models have been applied to the southern hemisphere to spatially reconstruct past vegetation – a gap which we are working hard to bridge. Through this new angle of modelling, we are working to refine the spatial dimension of past vegetation reconstruction from pollen, complementing previous analyses of the 'what' and 'how much' with a spatially explicit understanding of the 'where' of vegetation changes.

These three pillars underpin our next steps to deepen our understanding of how both humans and climate have modulated southeastern Australia's ancient cultural landscape. By working with Traditional Owners throughout the research process, we can build a scientifically and culturally valid picture of Australia's diverse biocultural landscapes. Revealing the history of Indigenous land management and fire practices can provide a solid foundation for navigating Australia's flammable future.

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SUPPLEMENTARY INFORMATION: BEYOND THE BACK PAGE

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"On the [twenty-ninth] day of the month of [March]

In an early year of a decade not too long before our own

The human race suddenly encountered a deadly threat to its very existence

And this terrifying enemy surfaced as such enemies often do

In the seemingly most innocent and unlikely of places."
(Little Shop of Horrors, 1986).

As the world stopped and we withdrew into our safe places to ride out the biggest global health crisis of a century, our attention, collectively, was turned to those things that truly mattered most mastering sourdough bread, learning the Blinding Lights TikTok dance, and podcasting. Having been a sourdough baker well before the pandemic struck (my starter, Cecil, was in great shape for the long lockdown days), and about as much dance 'coordination' as Peter Garrett, my only option was podcasting.

Late in 2019, I had stepped into an Education and Engagement (E&E) Coordinator role with CABAH. This position allowed me to explore the Venn diagram intersection between science communication, media, and education. And, well before our front doors were slammed shut in 2020, together with Julie Matarszyk and Zoe Taylor, the idea of a podcast series exploring the breadth of research being undertaken within CABAH had begun to fizzle at the back of my brain.

With the walls of my not-so-spacious one bedroom, one bathroom, and broom cupboard rental beginning to close in on me by April 2020, my days spent staring at the four walls with my co-worker cat (N.B., not a reliable individual, always showed up late, and mostly asleep) allowed those first ideas to begin to take shape. The then-untitled series would interview CABAH members at different career stages about one of their recently published research articles to guide the conversation. The aim was to try and get the interviewees to talk about their research in a more relaxed, less academic way, allowing us to learn about them and their stories, rather than just the research. And so, Supplementary Information was born.

Having pitched this format to the E&E team, Julie and Zoe both suggested that I complete the online podcasting course run through the University of Canberra. This course would give me the bare bones of how to design, construct, market and distribute podcasts, as well as workshop our podcasting ideas with the course coordinator. Safe to say, by the end of the course I probably only knew enough to be dangerous.

Feeling a bit overwhelmed at where to begin in this whole endeavour, Zoe skillfully introduced me to someone who would go on to become the single most influential member of the Supp Info team, Ms Jacqueline Wales. Those within CABAH would know Jacqui as the Media & Communications Coordinator taking over from Zoe Taylor, but in 2020 Jacqui was a new face at CABAH HQ. Jacqui would teach me all about interview technique, sound mixing, and publishing, and would end up being both the producer and comms expert for Supp Info.

All good things come in pairs: Batman and Robin, Roy and HG, Bert and Zenobia. And the same applies to podcasting. The power of a dynamic duo enables the listener to become part of a conversation, rather than just being talked at by a monotonous voice. I was so very grateful that when I asked Dr Kelsie Long (a CABAH postdoc at the ANU, and fellow Lake Mungo researcher), she jumped at the chance without hesitation. I can remember a wet weekend following the release of lockdown conditions in September 2020 when Kelsie and I recorded our first snippets of dialogue to put together an introduction minisode introducing ourselves and the podcast. It was harder, I think, than both of us anticipated. But I knew at that point that not only was Kelsie the right choice as co-host, but that we were going to have a cracker of a time working on this project together.

Our next challenge was to coordinate a list of guests for us to interview for our premiere season. While we wanted to ensure that we had wide representation of all career levels, our goal was to shine a light on the Early Career Researcher (ECR) cohort within CABAH as much as possible. Ultimately, I think we were able to achieve that balance with five ECRs and two established researchers coming onboard with our little sci-comm adventure. I was, and still am, very grateful for our seven guests for agreeing to spend their time on us and share their knowledge with us and our listeners.

Given the spatial distribution of CABAH members across state and territory boundaries, and a pandemic still raging around the world, travelling to interview our guests was not really an option. So, we took to the communication

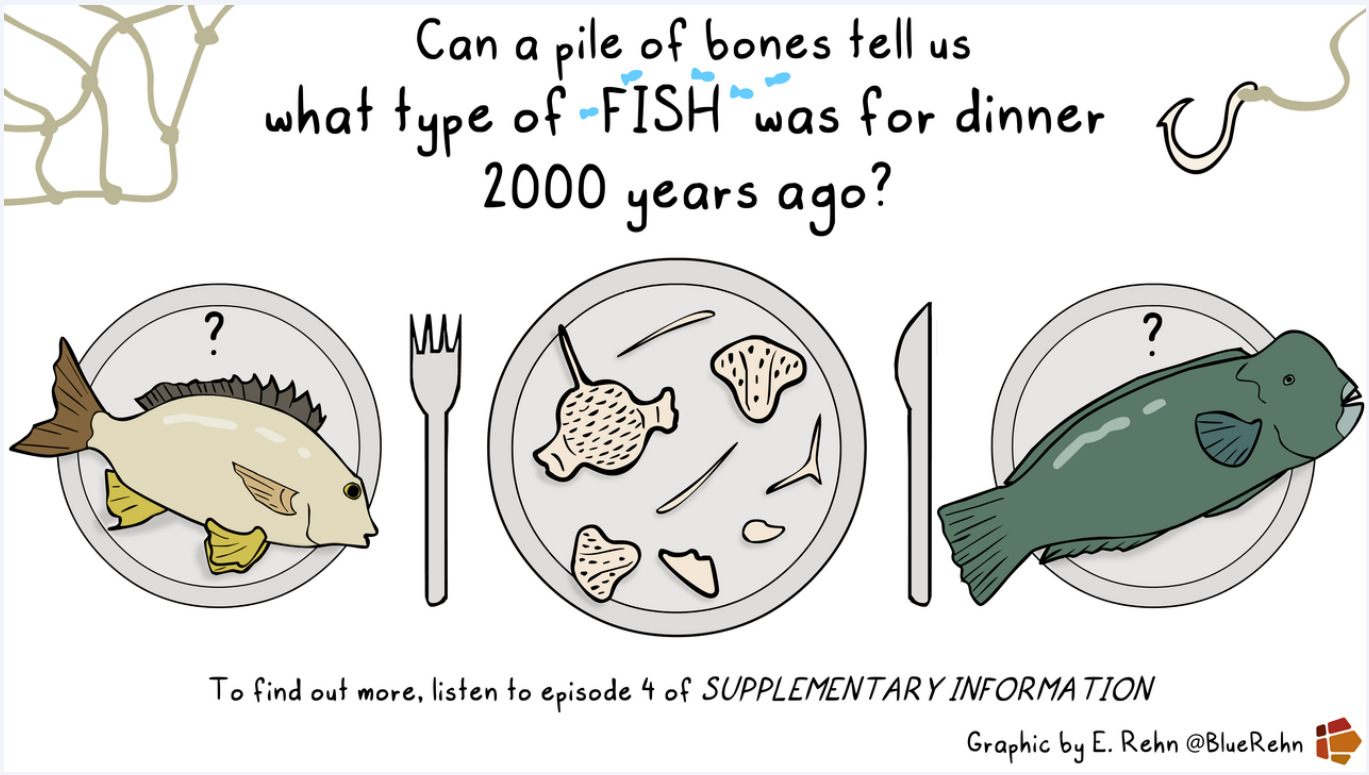

Figure 1: Promotional graphic by Dr. Emma Rehn for Episode 4: Fish for Thought with Ariana Lambrides who examines fossilised fish bones from archeological contexts to determine which fish were collected by people in the past.

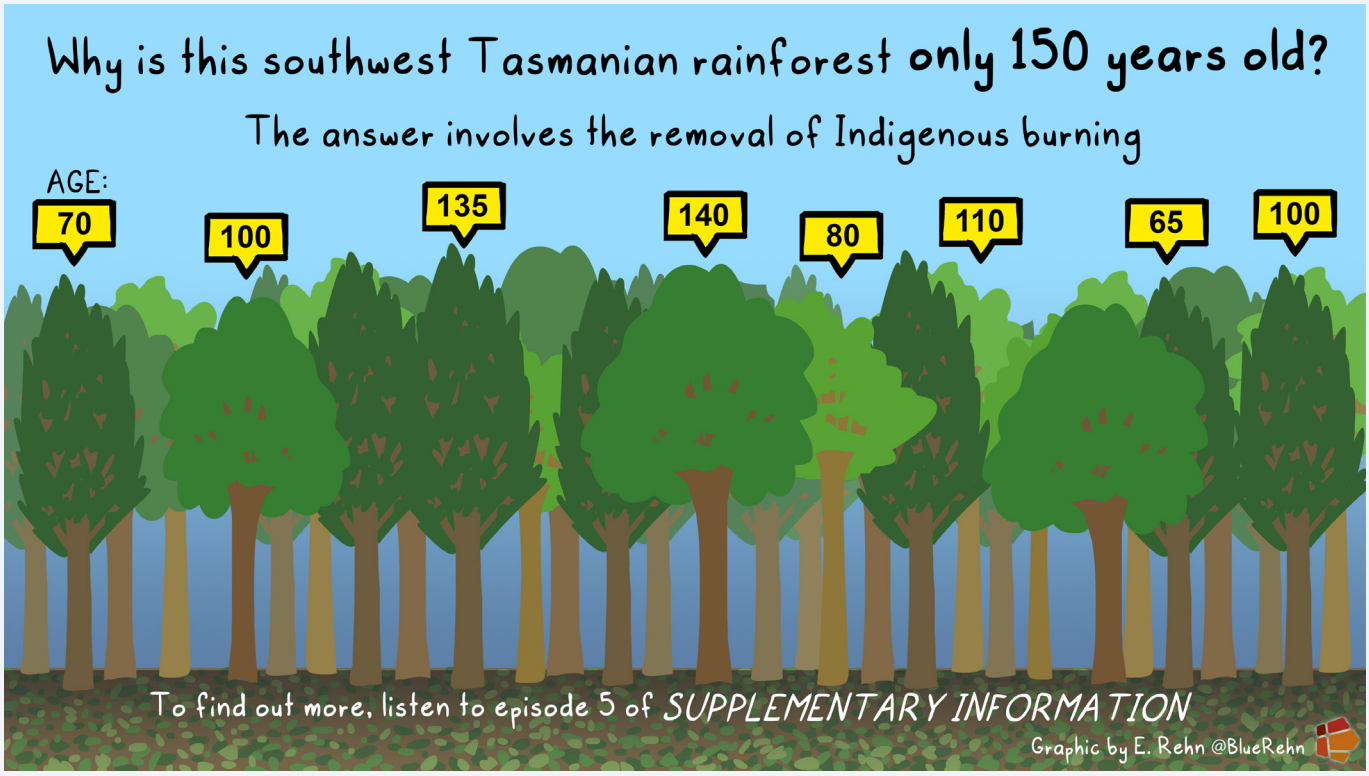

Figure 2: Promotional graphic by Dr. Emma Rehn for Episode 5: Rainforest Redux with Michael-Shawn Fletcher who used the age of rainforest trees to determine when patches of rainforest began to encroach into flammable moorland vegetation.

mode du jour of the pandemic and conducted all our interviews over Zoom. "Sorry, I think you're still on mute" was something that we all experienced throughout our discussions. But we figured it out by our last interview.

Over our seven episodes, Kelsie and I got to learn about such a wide diversity of research going on within the Centre. We began with understanding the lineage of Australia's dingoes with Kris Helgen, the impact of rewilding predators onto King Island with Matt Feilding, and conserving practice for ancient pottery with Holly Jones-Amin. We then went diving into ancient fisheries along the Queensland coast with Ariana Lambrides, the impact of Traditional Fire practice on controlling Tasmania's wet rainforests with Michael-Shawn Fletcher, a close-up look at pollen with Matthew Adeleye, and the seafaring adventures of possums across Wallacea's high seas with Shimona Kealy.

Having interviewed and mixed the episodes, the release of our podcast into the wild was expertly coordinated by Jacqui. Going above and beyond, Jacqui also designed text-based contributions to complement our audio offering. As the old adage goes, a picture paints a thousand words, and we were very fortunate that we were able to enlist the artistic talents of CABAH's own Dr Emma Rehn to turn our episodes into beautifully composed and informative infographics for the Epic Australia website. I still have a small printout of a swashbuckling cuscus on my office pin board.

Looking back on my time thinking, designing, interviewing, mixing for Supplementary Information, I am still amazed that the slick, professional product that we were able to deliver was the result of a lockdown brain-fart of a complete amateur. None of this would have been possible without the space that CABAH (and a global pandemic) had given me to spend the time on this pet project of mine over the course of a year. I also could not have done it without the support of the E&E team that encouraged and enabled me to undertake this work, Julie Matarscyk, Zoe Taylor, Jacqui Wales, my co-host Kelsie Long, and series illustrator Emma Rehn. Although I'm disappointed I never got to do a second series (a DECRA project got in the way), I remain immensely proud of what was achieved in our one season of Supplementary Information.

All episodes of Supplementary Information can be found on major streaming services such as Spotify and Apple podcasts.

Episode 1:
The Dogma of Dingoes with Kris Helgen

Episode 2:
Rewild the Isles with Matthew Fielding

Episode 3:
Pots and Puzzles with Holly Jones-Amin

Episode 4:
Fish for Thought with Ariana Lambrides

Episode 5:
Rainforest Redux with
Michael-Shawn Fletcher

Episode 6:
Pollen Potential with Matthew Adeleye

Episode 7:
Marsupials on the Move with Shimona Kealy

LUNETTES AND THEIR HISTORY: LANDSCAPE AND CLIMATE CHANGE IN WESTERN VICTORIA

Victoria Schwarz

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Little is known about the environmental history of Western Victoria and the Wimmera river system. Therefore, in January 2025, we, three researchers from Monash University (Melbourne, Australia) in collaboration with the Barengi Gadjin Land Council, started the first of multiple fieldtrips to investigate changes in landscape and climate in the Wimmera catchment during the late Quaternary and Anthropocene. After undertaking fieldwork around Gariwerd/the Grampians Ranges during my Master's at the University of Tuebingen (Germany), I (Victoria Schwarz) was very interested in starting my PhD focusing on the downstream reaches of the Wimmera at Monash University under the supervision of Kathryn Fitzsimmons. It was a great chance to conduct this fieldwork with the help of Rory Ferguson right at the beginning of the project.

Starting from Monash University, we drove past Gariwerd/the Grampians Ranges to the northern part of the Wimmera catchment. The Wimmera catchment is the biggest inland draining river in Victoria. Its headwaters are in the Pyrenees Ranges and tributaries originate from Gariwerd/the Grampians Ranges and the Black Ranges. For us, the area further downstream is of major interest, as it is an important agricultural region which is vulnerable to drought, flood, and fire and it lies close to the present-day dryland margin with a widespread presence of dryland landforms. North of the Little Desert, multiple palaeochannels, billabongs, and remains of lakes, potentially formerly connected to the Wimmera, are of interest. North of Jeparit, the Wimmera flows into Lake Hindmarsh (Gurru), an important recreational location in the area. During higher water availability, its waters can fill up Lake Albacutya (Ngalpakatia/Ngelpagutya) and flow even further north into the Wirrengren Plain in the Wyperfeld National Park.

It is hard to imagine that people used to swim in the now dry Lake Albacutya (Ngalpakatia/Ngelpagutya) in the 1970s, while this year the region is threatened by ongoing bushfires in the Little Desert and in Gariwerd/the Grampians Ranges. Both can be related to climate change and land use practises putting the region under increasing pressure and resulting in the decrease of valuable wetlands, such as reduced rainfall and the diversion of Wimmera water for agricultural use. As this area preserves valuable environmental archives, such as lunettes at the eastern lake shorelines, linear and parabolic dunes, source-bordering dunes, and fluvial deposits, this project aims to better understand the past hydroclimatic conditions and landscape response in order to elucidate the thresholds for landscape reactivation – and in doing so, to better help us understand how future climate change might impact this environment and provide baseline context for future land management.

We visited the shorelines of multiple lakes and former lakes to obtain an overview of the suitability of the different sites and their context in the landscape. We were glad to have a well-equipped 4WD to deal with the sandy tracks through the lunettes. Luckily, we were able to define very good sampling sites as well as exclude lakes from our list which are not as suitable. The Wyperfeld National Park, in particular, with its multiple former lakes and lunettes impressed us with its nature and the rich environmental history preserved there.

For sample and data collection, we spent a couple of days at Lake Hindmarsh (Gurru), which has multiple lunettes and shorelines which will tell us more about past lake levels and the timing of water availability. To start with, we collected high resolution real-time kinematic (RTK) GPS elevation transects running perpendicular to the lake's shoreline. Through this, we documented the relative height of the shorelines to the lake and will be able to assess past lake levels and water volumes. This also helps us to develop a suitable sampling strategy. At the south-eastern margin of Lake Hindmarsh (Gurru), we placed our sampling locations along the transect at the crest of the lunettes and within the interdune area between two lunettes. Sampling was thereby conducted by either using a profile or by sampling with a hand-auger. In both cases, we collected sediment samples in a ~10 cm resolution for sediment characterisation including grainsize. For dating, we will use optically stimulated luminescence (OSL) dating. OSL dating uses the accumulation of trapped charge in quartz or feldspar grains during the exposure to ionizing radiation while being deposited. The exposure to light results in a reset of this signal. Therefore, we collected the dating samples in stainless steel tubes by hammering them into the sediment. Through this, any light exposure is avoided, and the sample will later be opened and processed under

Figure 1: View from the second lunette at Lake Hindmarsh over the first lunette (rise behind the cars) to the lake.

Figure 2: Sampling site at Lake Hindmarsh, using four small profiles to cover the entire depth and reduce the impact to the landscape.

Figure 3: Taking sediment and OSL samples along a small trench.

Figure 4: Sampling while digging up the hand auger which got stuck at 2 m depth.

Top – Figure 5: A pregnant stumpy tail just walked past us.

Middle – Figure 6: Enormous outcrop of the major lunette of the Wirrengren Plain in the north of the Wyperfeld National Park.

Bottom – Figure 7: Residuals of a lunette at Lake Albacutya, valuable for sampling and mapping of different units within the lunette.

red light, which does not reset the signal. Once, our auger got stuck and luckily, we were able to dig a 2 m hole to get it up again with an intact sample.

Now, we are looking forward to analysing our samples and the GPS data to get first insights in the environmental history of the Wimmera region. Despite the recent bushfires that have sadly impacted this region, we will come back as there is so much more to do in this amazing landscape!

We acknowledge the deep and continued connection held by the Wotjobaluk people, as the Traditional Owners, to Country in the Wimmera region. We would like to thank the Barengi Gadjin Land Council for their support in the field and the ongoing collaboration.

This fieldwork was funded through Monash University startup funding awarded to Kathryn Fitzsimmons. The PhD research of Victoria Schwarz is supported through an Australian Government Research Training Program (RTP) Scholarship.

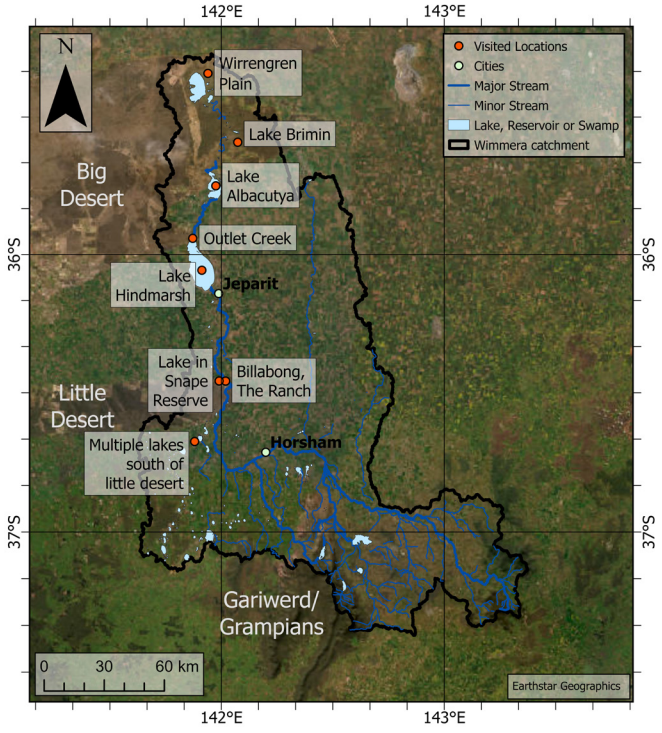

Figure 8: Overview of the locations visited during the fieldwork including the catchment boundary and the major water bodies (adapted from Geofabric; Bureau of Meteorology, 2022).

PALAEOENVIRONMENTS AND LANDSCAPE CHANGE AT LAKE MUNGO, WILLANDRA LAKES

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The Willandra Lakes Region World Heritage Area is situated within the semi-arid zone of Australia's arid core and is home to the Barkandji/Paakantyi, Ngiyampaa and Mutthi Mutthi Traditional Tribal Groups. The region is one of the oldest occupied localities by Australia's First People (~55,000 ka to present; Stern 2020) and was made famous by the discovery of the oldest-known burials of the First Australians, dating to ~40–42 ka ago (Bowler et al., 2003; Jankowski et al., 2020). This heritage significance ultimately led to Willandra's inscription on the UNESCO World Heritage Register in 1981.

The Willandra Lakes are located in the Millewa-Barka (Murray-Darling) basin of southwestern New South Wales (NSW). The Willandra Lakes are a large relict overflow system situated among channels, aeolian dunes, and lunettes (crescentic source bordering dune; Figure 1) (Bowler, 1998). The Willandra lakes themselves are characterised by basins with shallow profiles, northwest/south-easterly orientated sub-elliptical morphology and a greatly rising eastern lunette (Bowler, 1998). During periods of more effective water flow and precipitation in the past, the now-dry Willandra Lakes were the largest inland lake system within NSW covering a total area

Figure 1: Lake Mungo lunette overlooking the lakeshore and basin.

of ~1,088 km². The system comprised of a series of five major, and numerous smaller lake basins. From the northeast, the major lakes are Lake Mulurulu, Lake Garnpung, Lake Leaghur, Lake Mungo, and Lake Arumpo. Each successive lake, with the exception of Mungo, was filled via the Willandra Creek, conducting overflowing water from its northern adjacent lake. Lake Mungo, by contrast, was filled by an inlet channel from Lake Leaghur rather than the Willandra Creek (Bowler et al., 2012; Stern, 2020).

Despite the long history of Western scientific endeavour within the Willandra, scientific investigations of past environmental change have focused almost exclusively on lunette development as a proxy for hydrologic change (Figure 1) (Bowler 1971, 1998; Bowler et al., 2003, 2012; Fitzsimmons et al., 2014, 2015; Barrows et al., 2020; Jankowski et al., 2020). Given the vast area covered by lake floor in the Willandra, it is surprising that there are currently no published accounts investigating the palaeoenvironmental record preserved within these lacustrine settings. Bowler (1998) outlines a series of tractor trenches excavated from the southern end of the Mungo lunette near the Mungo Man and Mungo lady burials out onto the lake floor, but this work has never been published.

It is anticipated that the study, analysis and interpretation of the lakebed records would be complex due to the dynamic palaeoenvironmental history of Willandra's lakes. One of the key challenges likely to be encountered within the central basin facies is the complex stratigraphic record produced by episodic deflation during periods of low, fluctuating lake levels. During these periods, the subaerially exposed, clay-rich lake floor sediments were broken up and entrained into the adjacent lunette forming as sand-sized pellets of clay (Bowler, 1971). Despite this partial erosion of the record, the remaining stratigraphic sequence can be investigated and interpreted in the same way as the discrete time packages preserved within the adjacent lunettes — through detailed, high-resolution sedimentological, palaeoecological and geochronological sampling. At present, we solely rely upon lunette sedimentary archives for understanding hydrological change in the Willandra.

PALAEOVEGETATION RESEARCH

Palaeovegetation studies use the fossilised remains of plant life or matter, such as pollen, phytoliths, charcoal, starches, spores, and other residues, to reconstruct past vegetation communities. Currently, no systematic investigation of palaeovegetation dynamics has been reported from neither archaeological nor palaeoenvironmental contexts within the Willandra. This paucity of palaeovegetation research in the Willandra is not unusual for arid Australia or the Millewa-Barka (Murray-Darling) basin. It seems that the lack of research endeavour into palaeovegetation dynamics within the region is often based upon long-held assumptions that preservation conditions are too degrading, archives are too complex, and/or river and waterbodies are too shallow to be of great importance (Gell et al., 1994; Cupper, 2005; Gell & Reid, 2014; Forbes, 2020). As such, we know very little about how vegetation communities changed in concert with changing lake-level conditions within the Willandra.

The study of pollen and phytoliths are two well-established subfields in palaeovegetation research, which together can be used to provide complementary datasets. For example, phytoliths can capture plant taxa under-represented and with lower taxonomic resolution in pollen records, such as *Poaceae* (grasses). Pollen, in turn, can capture woody taxa such as trees and shrubs, which are often under-represented and have lower taxonomic resolution in phytolith records (Cupper, 2005; Piperno, 2006; Strömberg, 2018). Pollen has been traditionally privileged, globally and in Australasia, over other plant fossils in palaeoecology (Turnbull et al., 2023). Pollen grains have aerodynamic morphologies that are wind-pollinated, typically reflecting regional vegetation dynamics (Strömberg, 2018). Whereas phytoliths are typically directly deposited into the sediment, representing highly localised vegetation communities within the vicinity of collection (Piperno, 2006; Pearsall, 2014). With this in mind, pollen records from Lake Mungo, and the Willandra more broadly, could include local vegetal input from the foreshore, lunette and surrounding dunes, and regional vegetal input blown in from the larger Millewa-Barka basin system. Phytoliths likely only reflect the local vegetal input, allowing us to detangle these two scales of vegetal input.

The preservation of pollen and other organic material in the arid and semi-arid zones is often considered to be suboptimal (Cadd et al., 2024). The preservation of pollen typically occurs in consistently wet, anaerobic conditions such as lakes, swamps, and lagoons. In contrast, pollen is known to experience degradation, dissolution, and chemical breakdown aided by microbial action in the aerobic conditions above the water table in many arid settings (Strömberg, 2018). Yet, this apparent ubiquitous degradation is not universally guaranteed, e.g., in Mithaka Country, northwest of the Millewa-Barka, sediment cores taken from arid Channel Country have a well-preserved pollen record (Moss et al., 2023). Similarly, ~150km west of Mungo, Cupper (2005) was able to extract a Pleistocene-Holocene pollen record from the ephemeral Darling Anabrach Lakes. Yet, in instances where pollen and charcoal have decayed, the

biogenic silica composition of phytoliths resists decay, preserving them in high abundances in a wide range of depositional environments, including arid ones (Hopps, 1977; Coughenour, 1985). Preliminary insights from unpublished pilot studies (publications forthcoming) reveal that pollen, phytoliths, and starches do indeed preserve in various geogenic and anthropogenic contexts from the Willandra, such as geogenic sections, hearths, and grindstones (Fullagar et al., 2015; Cadd et al., 2024; Jankowski et al., 2024; Turnbull et al., 2024).

SEDIMENT CORING

The Willandra Lakes Region Aboriginal Advisory Group, comprising of elected representatives from Barkandji/Paakantyi, Ngiyampaa and Mutthi Mutthi Peoples, has long recognised these gaps in the research endeavour on their Country. Therefore, it has been their shared goal with scientists to core the lakebeds of the Willandra, starting with Lake Mungo. Our team from the University of Wollongong (UoW) first approached the Aboriginal Advisory Group in 2018 to discuss the potential to collect sediment core samples from the Mungo lake floor. We have enthusiastically developed this research opportunity to integrate Indigenous perspectives with multidisciplinary scientific methods to better understand shifting lake conditions in the Willandra. Despite some setbacks along the way and a global pandemic in the interim, a series of cores were finally collected from Lake Mungo, Mungo National Park, in February 2024.

Unfortunately for our team, it turns out our luck would be continuously tested if we wanted to take sediment cores from Lake Mungo. Originally scheduled for October 2023, our first scheduled trip to collect the Mungo cores was washed out by a steady drizzle of rain the week before, which culminated in a 6-inch downpour two days prior to our scheduled fieldwork. Needless to say, the ~80 km of unsealed Arumpo Road was swiftly closed by Wentworth Shire Council, definitively ending our fieldwork plans before they had even started. We therefore pushed back our plans to February 2024 to coincide with the arrival of a new, rope-threaded coring equipment that recently arrived at UoW from Germany. This inopportunely coincided with a week of 40 C+ weather.

After arriving the night before, we headed out nice and early to Lake Mungo to set up for fieldwork. After everything was organised, we discovered the connector of our new coring rods was too small to attach to our Whacker motor. Without the proper connector, we had no way to push the steel barrel into the hard clay floor of Lake Mungo. We were distraught. Had the UoW team wasted everyone's time and driven 13 hours to the Willandra for this fieldwork not to go ahead?

We immediately began a Quaternary phone tree, largely thanks to Haidee's network of colleagues with a whacker on the eastern seaboard between Sydney and Adelaide, to attempt to find a solution. We began with our colleagues at UoW, Tim Cohen and Sam Marx, to work out how we had ended up with the wrong connection — and it turned out we had ordered the wrong size. After this, we contacted Alex Francke to see if either the University of Adelaide or Flinders University (the closest universities to Mungo, only 500 km away) might have the correct adaptor. Alex diligently checked the field stores but discovered that their system had a larger barrel. Alex had, however, purchased a similar Whacker system while working with Brad Pillans at the Australian National University (ANU) only a few years ago. We were told Brad had sold his system but were unsure of who to. After a few more phone calls, it was determined that Simon Haberle had bought Brad's Whacker and that it may have the part to match our new rods. Unfortunately, things were looking grim again, as Simon was on remote fieldwork in Tasmania at the time. As luck would have it, though, another Alex was available to help — Alex Wall was able to check the ANU field store. Alex determined that ANU did indeed have the piece that we needed. The final obstacle was that ANU is a 1600 km round trip to Lake Mungo. Serayah Steele, a UoW Honours student, generously offered to drive to from Wollongong to Canberra, to pick up the connector and then drive 800 km to Balranald — all by the very next day.

With an extra pair of hands and the right equipment, the rest of the Lake Mungo coring went off without a hitch, even in the 40 C+ heat (Figures 2-8). This fieldwork corresponded with the 50th anniversary of Jim Bowler's chance finding of Mungo Man. As the late Mary Pappin explained, the Ancestors had revealed themselves all those years ago '...to walk with our people to help us with our struggle and to tell the rest of the world about our cultural identity with that land' (Pappin, 2006). The work we are doing in the Willandra aims to continue telling that story through the co-design of our research project with the First Nations communities of the area, ensuring the benefits are shared, equitable and responsible. Indigenous custodianship of biocultural landscapes is now better integrated into mainstream research practices in fields like archaeology and Quaternary sciences (e.g., Langford, 1983) and rarely contested. However, often biocultural landscape custodianship can be overlooked in geogenic settings, whereby this is perhaps more obvious to researchers working in explicitly anthropogenic settings. This can reinforce a natural-cultural divide at odds with Traditional Ecological Knowledge (TEK) (Cumpston et al., 2022) and cultural landscape theory (e.g., Sauer, 1927), in which the entire landscape is viewed and experienced

bioculturally. Nevertheless, on-Country Quaternary fieldwork should always involve co-designed research partnerships with First Nations communities.

Multiple terrestrial cores were taken from the dry lake basins using an open and closed barrel percussion whacker (Figures 5, 7-8). The team and Aboriginal Advisory Group members attending were pleased with how minimally invasive and cost-effective this method is, leaving only a small hole that is easily filled in. This was of high importance to the Community, as there needs to be little inadvertent harm caused to the fabric of this significant biocultural landscape, which can have important cultural traces eroding out of the surface. Duplicate cores were also taken for future education and engagement for the Community, along with photography, filming and drone footage of the fieldwork process.

WHAT IS NEXT?

Expert TEK of plant resources has been part of Barkandji/Paakantyi, Ngiyampaa and Mutthi Mutthi practice in managing past landscape changes. This TEK will inform our palaeoenvironmental interpretations moving forward. For palaeovegetation reconstructions, we have targeted microfossils such as pollen and phytolith for analyses. This firstly requires highly localised modern reference collections, vegetation surveys and analogues of flora and sediments to carry out accurate fossil interpretations (Turnbull et al., 2023).

Other analyses currently being explored to further investigate the sediment cores include Itrax X-ray fluorescence core scanning, optically stimulated luminescence (OSL) dating, radiocarbon dating, micromorphology and ostracod studies, amongst others.

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MT/NRJ/HC/SS offer our thanks to our fieldwork team/collaborators: Warren Clark, Colen Charles, Verna Eade-Pappin, Tanya Charles, Leanne Mitchell, Lawrence (Uey) Slade, and Anthony Taylor. Thanks are extended to Dan Rosendahl, Tressna Martin, Jo Gorman (World Heritage/NSW Parks), Tom Wakefield, Ian Wakefield

Top – Figure 2: First core location at Lake Mungo.

Middle – Figure 3: Second core location at Lake Mungo.

Bottom – Figure 4: Special site visitor.

Top Left – Figure 5: Opening the core barrel.
Left – Figure 6: Examining the sediments.
Above – Figure 7: Cleaning up the core.
Below – Figure 8: Close-up of cleaning the core.

(Top Hut Station), and our other frequent collaborators: Nicola Stern, Adrian G. Parker, and Alison Crowther. We also appreciate Tim Cohen's equipment training and expertise. Finally, a massive thank you to the eastern coast Quaternary Whacker phone tree — without which this fieldwork would have literally been impossible.

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AQUA'S MENTORING PROGRAM – FOUR YEARS IN!

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The AQUA mentoring program is a semi-structured program designed to provide guidance and support to early career researchers, promote equity and diversity, and improve collegiality within the Quaternary community. The program operates every second year, to align with AQUA's biennial meetings, and is explicitly informal and community-driven. AQUA issues invitations to join, with a small questionnaire to aid with matching mentors and mentees. After matching, it is up to mentors and mentees to determine how they would like to proceed with their mentoring relationship, although we do encourage regular meetings. To date, 17 AQUA early career researchers (ECRs) have received mentorship from members of the AQUA community. End-of-program feedback for the 2022 and 2024 programs has suggested that both mentors and mentees have felt that the program was worthwhile. In particular, mentees have highlighted that getting support from academics outside of their supervision team was really valuable, and both mentors and mentees have indicated that they expect the mentoring relationship to continue beyond the duration of the program.

The next iteration of the mentoring program will take place in 2026, and AQUA members can expect to receive an invitation to participate later this year. We would like to take this opportunity to warmly thank everyone who has participated, especially those mentors who volunteered for both the 2022 and 2024 iterations of the program. AQUA is built on community, and we hope that the mentoring program is helping to build stronger links between Quaternary scientists. We hope to see large proportion of the AQUA community participate in 2026!

AN ADVENTURE OUT TO CASS: AN INTEGRATED WISH WORKSHOP

Caeli Connolly

University of Canterbury, Christchurch, Aotearoa/New Zealand

This February, I attended my first workshop for the INQUA network "Warm Intervals in the Southern Hemisphere (WiSH)", held at the University of Canterbury Cass Field Station. In this scenic setting amid the Southern Alps, a team of students, academics, and scientists from across Aotearoa | New Zealand and Australia met to share their research areas and work together to identify available records and knowledge gaps across current and previous interglacial periods. Talks were given on a wide variety of topics covering glacial and deglacial responses and changes, reconstructing vegetation and fire regimes, organic metals in speleothems, and past Indigenous populations.

As soon as the presentations were completed, the group split into three subgroups to discuss and highlight commonalities across different research fields. One group focused on gaps in the glacial record, the second discussed warm interglacial time periods, and the final group explored human activity relating to climate change. The subgroups were tasked with identifying gaps in their field of knowledge, highlighting what data already exist, determining who has access to information, and deciding what data still need to be collected. The whole team came together again to share the results of their subgroup's discussion, give feedback, and determine a timeline for proposed publications.

During the afternoon, we took a mini field trip to learn about the glacial features visible in the landscape. We looked at moraines, a glacial pond, and a bog that surrounded the field station. After the field trip, attendees continued to share research ideas and connect with one another over wine and cheese. The WiSH workshop provided a relaxed, yet focused atmosphere for bringing together ideas, and I am excited to see the results of our collaborations and to be a part of future WiSH research. For further information on WiSH, please visit our webpages here: warmintervalssh.wordpress.com and inqua.org/projects/project-2439-my-warm-intervals-in-the-southern-hemisphere-wish

Figure 2: WiSH workshop group photo. From left to right, bottom row: Jamie Shulmeister, Caeli Connolly, Aylin de Campo, David Fink. Middle row: Jo Hansen, Haidee Cadd, Matt Ryan. Top row: Matiu Prebble, Sebastian Hoepker, Alan Williams, Greer Gilmer, Lydia Mackenzie, Gwen Ferguson, Caroline Mather, Nick Roberts. (Photo credit: Jamie Shulmeister).

Figure 1: Pictured in the forefront is a glacial bog, with a lake and Southern Alps seen in the background. (Photo credit: Lydia Mackenzie).

THE MEETING OF THE DREAMING HELD BOTH AT LAKE MUNGO AND MILDURA

Patrick De Deckker

The Australian National University

On the weekend of 22 and 23 February 2025, a very significant meeting was held both at Lake Mungo (Saturday) and in Mildura (Sunday).

On the Saturday, a large group of people gathered early in the morning at the Mungo Visitor Centre after a visit to the Walls of China. Present were members of the three Traditional Owner groups (Mutthi Mutthi, Ngyiampaa, and Barkandji/ Paakantji Peoples), Jim Bowler and many members of his family, as well as many Australian people and also several from overseas. Jason Kelly (figure 1) performed a Welcome to Country dance that was followed by conversations to explore the Meaning of Mungo as seen through the eyes of Traditional Owners.

The following day in the Mildura Powerhouse, on the edge of the Murray River, over 200 people were present and many presentations were held, including a Welcome to Country with a smoking ceremony.

Various topics were presented, including a very important one entitled "Lake Mungo Reflections" that followed a presentation by Jim Bowler. Several short (and old) movies were also shown. In the afternoon, an important session of "Education" was held, that was followed by presentations on the "Meaning of the Dreaming" by Tom Griffiths, Greg Campbell, Peter Sheehan, and Billy Griffiths.

Afterwards, a session entitled "Deep Listening" was held with talks by Jason Kelly, a message by Uncle Shane Charles and music by Shane Howard that presented a new song on Mungo and its meaning.

Top – Figure 1: Jason Kelly leading the ceremonial group.

Bottom – Figure 2: Jim and Joan Bowler with Jason Kelly and others.

Jim Bowler took the stage once more to discuss the geological and geomorphological history of Mungo through time, going back to Tertiary times.

The meeting ended with a discussion of "Ways forward and the Meaning of the Dreaming Globally". A one-page document was eventually presented to the audience providing some "Reflections on a Year of Dialogue". In addition, a one-minute video on YouTube appeared a week later that reported on the meeting in Mildura. It is available here: youtu.be/HDtN6bSVtGU?si=5BtXLH6-3u34Bsyr

A RECORD OF LATE HOLOCENE DUNE DEVELOPMENT ON FLINDERS ISLAND

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Marshall Bay is a 10 km wide west-southwest-facing embayment on the central west coast of Flinders Island, located in the Bass Strait between Victoria and Tasmania. It features a single low-angle beach with granite outcrops to the north and south (Figure1). The entire length of the beach is uninterrupted except for the isolated granite outcrop of Marshall Rock. A largely vegetated dune field covering approximately 1200 ha first described by Kershaw and Sutherland (1972) extends from a large coastal foredune inland for more than 1.8 km in places. The dune field consists of three main units (Sloss et al., 2012):

1. Established Foredune: a single large steep sided dune ridge dissected by east-west trending gullies that backs onto the modern beach and intertidal zone. The beach has a very low angle and wide intertidal zone; the foredune has a steep seaward face with numerous small blowouts.
2. Confused hummocky dunes in a complex terrain of hummocks and swales, short parabolic dunes, and stabilised blowouts. These extend from the immediate east of the foredune to c. 200 m inland.
3. Inland long-walled parabolic dunes with elongated profiles extending 1.5-2 km inland of the present Marshall Beach, rising to approximately 23 m above sea level (asl). These dunes are arcuate, with steeply sloping ridges associated with intervening large poorly drained areas which have been mapped as swamps such as the 6 ha North Curves Lagoon. They rise onto an old palaeo (last interglacial?) shoreline at the western edge of the low limestone bench at c.7-8 m asl.

The focus of this report is the exposed southern face of an old sand pit at the eastern (inland) end of a large stabilised parabolic dune ridge, located approximately 1.18 km from Marshall Beach. The project was initiated as an environmental impact assessment for revitalised extraction of lime sands from the dune ridge. As part of the project, the internal structure of the dune ridge exposed in the cutting was described and a sample was taken for OSL dating to gauge the age and significance of dune formation at this site.

DUNE STRUCTURE AND SEDIMENTOLOGY

The backwall of the old sand pit cuts through the northern slopes of one of the most prominent west to east aligned dunes in the Marshall Bay dune complex. The pit is located on the northern slope of the dune ridge. The dune overlies a flat Tertiary limestone bench that forms the floor of the pit. The pit face exposed the northern face of the dune, with the southern face still intact at the time of observations. The dune is composed of well sorted medium-grained sands. The sands are dominated by fragments of marine organisms and has a high calcium carbonate content estimated to be >95%. The remaining <5% is composed of quartz sands. No charcoal was noted in the cutting.

At the top of the cutting is a 1 m thick sandy deposit (Figure 2), capped by a thin modern topsoil. A prominent but thin paleosol demarcates its base. The 20 cm thick paleosol forms the upper unit of a sand layer which is around 2 m thick and overlies a second paleosol at the top of the lowermost sand layer which makes up the bulk of the dune. Both the upper and lower paleosols are <20 cm thick chocolate brown discolorations within the sandy deposits. Their limited thickness is comparable to the thin modern topsoils that consist of an A-horizon grading into a slightly discoloured B horizon above white sands. Tree roots penetrate through the topsoil mat into underlying layers but are sparse in the lowermost layer. While all three dune deposits are calcium carbonate rich, tree root rhizoliths are only associated with the lowermost layer. The rhizoliths exposed in the dune face are up to 30 cm long and vary in thickness from <1 cm diameter tubes that have formed around roots to 5-10 cm wide cylindrical shapes that may have formed around near-surface large root systems or small stems and fallen branches. Dating of the rhizoliths was not considered as some of the larger specimens contain intact woody roots suggesting that these secondary carbonate depositional landforms may not be old. The lowermost sand layer was the most compact and hardest to dig and this compact and less permeable layer of the dune may have favoured rhizolith formation from dissolved carbonate sourced from the younger and more porous upper units.

METHODS AND RESULTS

The lowermost unit was sampled for OSL dating analysis. This was undertaken by digging a bench 50 cm wide into the face of the dune approximately 1 m below paleosol 2. The compact undisturbed sand was sampled with a thick plastic tube inserted vertically into the back of the cleaned face of the bench (see Figure 2). Care was taken to avoid roots. The sample was packaged in black tape and sent to the University of Wollongong Optical Dating Facility. Here, the core of the tube was sub-sampled and small quantities of quartz grains were extracted using an HCl wash to remove the dominant carbonate component. Single quartz grains were extracted using standard procedures and measured using the single aliquot regenerative dose protocol applied to those single grains. Equivalent dose (D_e) values for 151 grains were obtained. An age estimate of 2,875 ± 205 yr was calculated (Table 1).

DISCUSSION

Given the location of the study site near the easternmost (most inland) extent of a dune system almost 1.2 km from the present coastline, it was expected that the dune may have dated to around the Last Glacial Maximum c. 24-15 ka. This was a period when dunes were known to be active around the Bassian Plain and in inland Tasmania (Gardner et al., 2006; Duller and Augustinus, 2006; McIntosh et al., 2020). Therefore, it was somewhat of a surprise to find that the sample dates to the late Holocene and indicates a period of significant dune instability around 2800 years ago. The lack of podzolization of the dune profile at the study site supports the relatively youthful age of the deposits. The presence of the two thin paleosols within the 4 m of sand dune above the dated horizon indicate that after the initial stabilisation of the lower 4.5 m tall dune by vegetation some time after 2800 years ago, there were two periods of smaller-scale dune activity. The inland dunes currently host a thick coastal scrub complex cover dominated by *Leptospermum glaucescens* and *Acacia longifolia* and show no signs of recent natural instability apart from very minor wind deflation and tree burial from the exposed pit face. Therefore, the presence of the relatively young Holocene dunes at this location implies a period of significant enhanced dune activity around 2800 years ago.

Work by Gao et al. (2024) observing modern active dunes on the Victorian coastline has highlighted the role vegetation cover can play in dune mobilisation. Interestingly, there has been an increase in vegetation

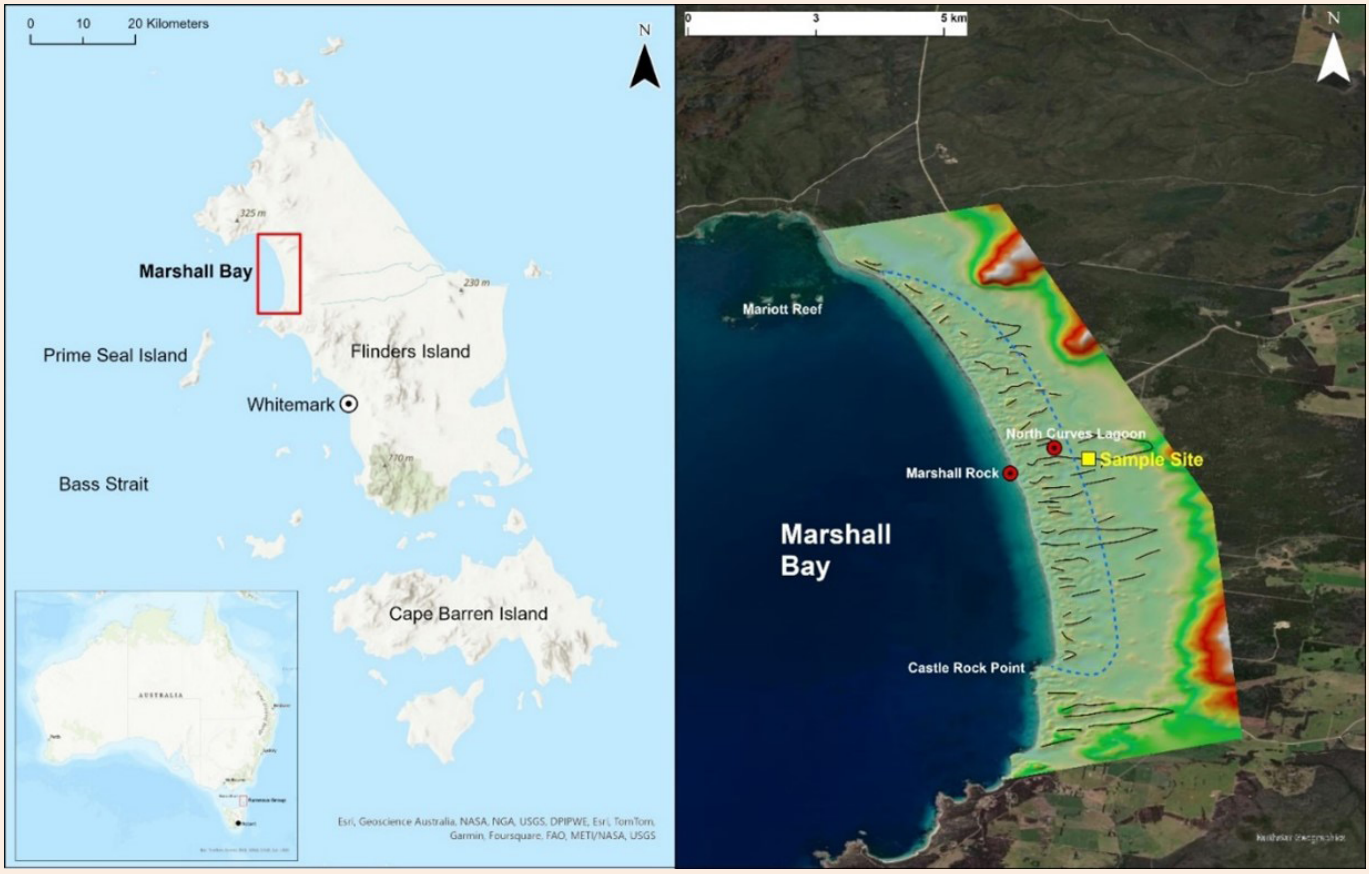
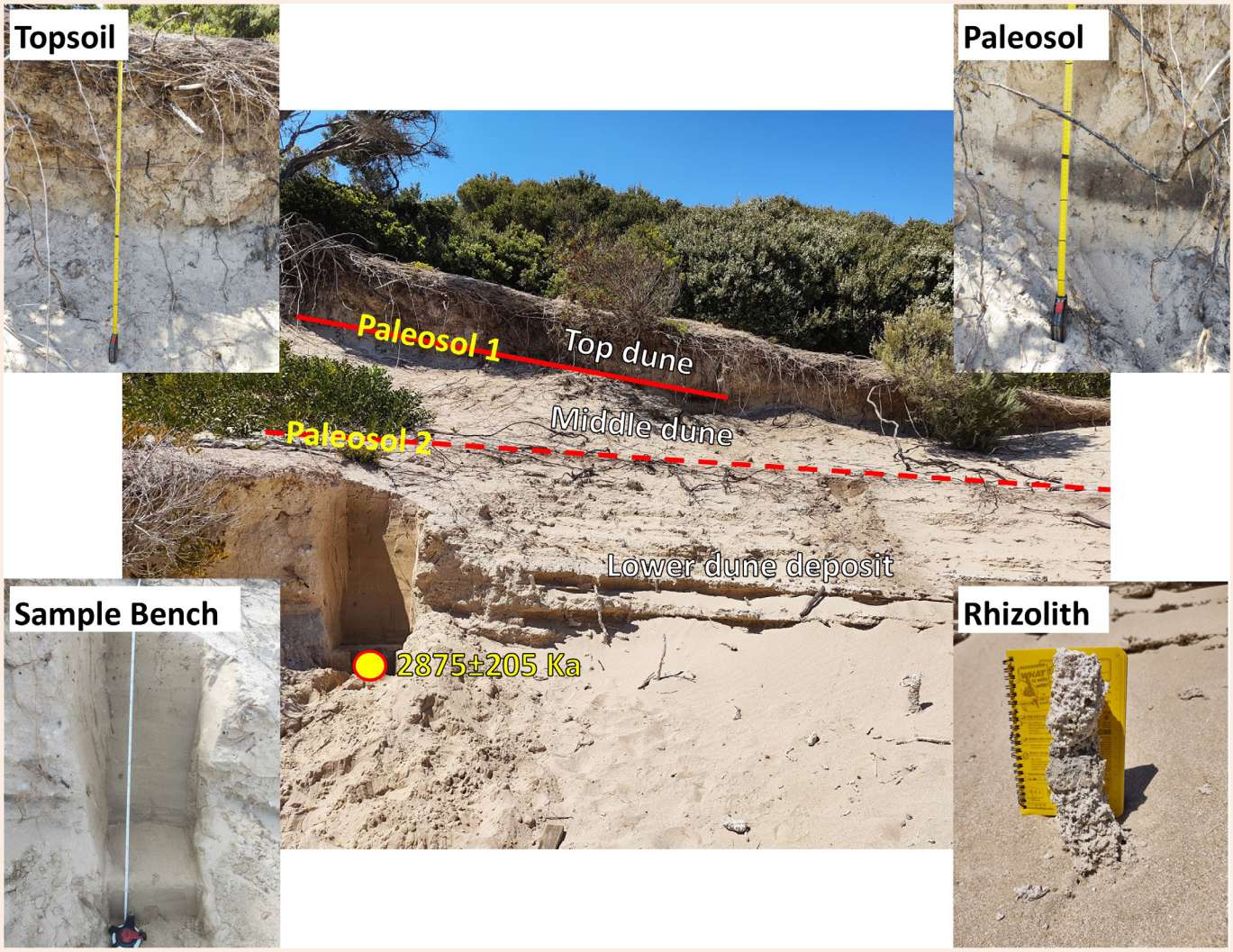


Figure 1: Location and detailed map of the study site at Marshall Bay, Flinders Island. The dotted blue line marks the approximate western edge of the limestone bench (old shoreline).



Top – Figure 2: View of the dune sampled showing layers described. Inset images provide details of important elements of the profile.

Bottom – Figure 3: A) View of Marshall Beach over the steep foredune towards Marshall Rock to the south. **B)** Loose sands and no soil development on a recently active foredune.

cover on Victorian coastal dune systems over the past few decades since the 1960s. While these authors were not specific about the cause of this increasing vegetation cover, it appears likely that the reduction in mean annual wind speeds over this time, coupled with a rise in temperature and therefore forest productivity in the region, may have encouraged vegetation expansion and dune stability over the past couple of decades.

We hypothesise that there was a short-lived climatic event around 2800 yr BP that led either to vegetation loss triggering dune remobilisation or dune re-mobilisation by wind or coastal processes. The lack of charcoal in the dune deposits and the presence of thin pale paleosols and modern topsoils at the site implies that coastal scrubland has been the dominant vegetation since the dunes formed. It appears unlikely that small temperature or precipitation changes could dramatically impact the stable drought- and wind-tolerant coastal scrub complex (Kitchener and Harris, 2013). A change in wind speed or changes to coastal processes are the more likely explanations for dune development in this area. The dunes which formed around 2800 years ago dwarf the currently active dunes in the area, implying that if wind was the key factor in large dune formation, then wind speeds must have been significantly stronger than at present to have deflated sands off Marshall Bay beach or from pre-existing near-shore dune ridges to have redeposited so much sediment so far inland.

It is noteworthy that studies of the Australian coastline have indicated that during the mid-Holocene (a period spanning 7000-2000 years ago; Sloss et al., 2007; Lewis et al., 2013), sea levels appear to have been 1-1.5 m higher than at present and may have oscillated (Baker and Haworth, 1997; Haworth et al., 2002; Lewis et al., 2008). The first highstand spanned c. 7000-5000 years ago, and a second smaller highstand peaked c. 3000 years ago. DaSilva et al. (2024) noted that with sea level rise, beaches may be eroded at the coastal/dune interface, generating sediment that may be deflated to enlarge inland dune systems. There is no evidence of extensive dune ridges inland of this study site indicative of LGM and older Quaternary dune development. This is in contrast with dunes at other sites in the wider region (Duller and Augustinus, 2006; Harris et al., 2009; McIntosh et al., 2020), suggesting that dune formation on the western coast of Flinders Island occurred only in a Holocene coastal setting, rather than during the period when Bass Strait was a flat, dry semi-desert plain.

Table 1: Markarna 1 sample results.

LABORATORY CODE	LC113
ENVIRONMENTAL DOSE RATE	
Water content (%)	7 ± 2
Beta dose rate (Gy/ka)	0.32 ± 0.01
Gamma dose rate (Gy/ka)	0.22 ± 0.01
Cosmic-ray dose rate (Gy/ka)	0.14 ± 0.01
Internal alpha dose rate	0.03 ± 0.01
Total dose rate (Gy/ka)	0.71 ± 0.03
EQUIVALENT DOSE (D_e)	
Central age model (CAM) (Gy)	2.05 ± 0.11
Overdispersion (%)	48 ± 4
Normalised median absolute deviation + CAM (nMAD CAM) (Gy)	1.98 ± 0.06
Overdispersion (%)	18 ± 3
AGE	
CAM age (years)	2,875 ± 205
nMAD CAM age (years)	2,785 ± 150

SUMMARY

The extensive dunes at Marshall Bay appear to date to the late Holocene and are of coastal origin. This contrasts with dune systems elsewhere around Bass Strait that indicate dune formation during the late Last Glacial under dry continental (semi-arid) conditions prior to the flooding of the Bassian Plain. The conditions that triggered dune development at Marshall Bay is likely to be a period of oscillating sea levels promoting beach erosion around 4500-3000 years ago that increased sediment supply. The presence of two thin paleosols within the dune post-dating 2800 years ago implies three periods of dune instability, separated by hundreds of years.

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THESIS ABSTRACTS

USING ANCIENT DNA AND NATURAL HISTORY COLLECTIONS TO INVESTIGATE DRIVERS OF DIVERSITY AND DISTRIBUTION IN AUSTRALIAN MAMMALS DURING THE QUATERNARY PERIOD

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Australia has undergone severe ecosystem modifications within the last 200 years since European colonisation. The ongoing impacts of European colonisation have contributed to the rapid extinction of nearly 10% of terrestrial endemic mammalian fauna in Australia (~30 species). The biodiversity present prior to European arrival was vastly different to what is present today. Similarly, the distribution and ecology of modern animal populations does not represent their historical distribution and ecology prior to population declines and extinctions. The major ecosystem modifications seen in Australia cause issues with resolving taxonomy of extinct and extant species, establishing historical distributions, understanding biodiversity prior to European arrival, determining accurate extinction estimates, and assessing genetic changes through time.

However, we are unable to use data from modern specimens and the fossil record alone as proxies for understanding the effects of major past events in Australia. Elsewhere in the world, ancient DNA has proven to be a powerful source of data to complement data from modern specimens and the fossil record, but until recently it has been challenging to undertake ancient DNA studies on Australian species. Recent advances have allowed us to analyse smaller quantities of DNA from lower quality fossils like those typically found in Australia. Additionally, museum collections are increasingly being used as sources of historical DNA, which is advantageous as many Australian species that became extinct soon after European arrival are only represented in these museum collections. In this thesis, I used ancient DNA and museum collections to resolve outstanding questions regarding taxonomy, genetic diversity, phylogeography, and demography of four distinct taxa that experienced severe range contractions or extinctions since European arrival.

This thesis provides a framework for producing large genetic datasets for other Australian taxa. With advances in ancient DNA techniques, we are able to use museum collections in population studies and identify cryptic diversity. Future studies should focus on developing non-destructive methods to recover genetic material from small specimens and incorporating radiocarbon analyses. My results suggest that biodiversity has fluctuated substantially since the Late Pleistocene in response to major climate events and biogeographic changes. I also argue that ancient DNA studies should not be carried out in isolation but should be part of a holistic approach that considers ancient biogeography.

PHYTOLITHS AS INDICATORS OF PALAEOENVIRONMENTAL CHANGE DURING THE MIDDLE PLEISTOCENE TRANSITION IN THE SO'A BASIN, FLORES

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Excavations in the So'a Basin, central Flores, have provided some of the earliest evidence of hominin activity in Wallacea. Stone tool evidence suggests that the likely ancestors of the small-bodied *Homo floresiensis* had reached the island over 1 million years ago. Understanding the palaeoenvironmental context of the arrival of genus *Homo* across the Wallace Line is crucial to understand the evolutionary context of *Homo floresiensis*.

The world of this early hominin was in flux, undergoing climate shifts and major ecological change driven by the Middle Pleistocene Transition (MPT). Observed between 1.2 and 0.7 Ma, the MPT is known to have led to the strengthening of global monsoon systems as well as the increased intensity and duration of glacial cycles. The effect of these climate shifts on the small insular ecosystem of Flores is uncertain, obscured by a ~400 ka gap in the fossil record. To generate much-needed palaeoenvironmental data for the So'a Basin during the MPT, phytolith analysis was conducted on 22 sediment samples from Tangi Talo and Mata Menge which provide a record of local vegetation spanning from >1.27 to >0.65 Ma.

The results of this study agree with previous palaeoenvironmental research, concluding that vegetation during the Early Pleistocene was likely more forested, with a significant expansion of grassland occurring after 1.27 Ma and ending prior to 1 Ma. It is likely that the increasingly arid and seasonal conditions generated by the MPT enabled the spread of tropical grasses and a great reduction in the presence of woody taxa in the So'a Basin. It is likely that savanna-like conditions predominated in the So'a Basin by the time of hominin arrival. These conditions remained relatively stable with no significant vegetation shifts recorded in the phytolith assemblages following 1 Ma. After this period, savanna with a nearby forests and wetland component persisted through the basin.

Overall, this study finds phytoliths to be very well preserved in the So'a Basin. There is significant potential for their application in archaeological and palaeontological research in future.

UPCOMING MEETINGS

2025

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New Zealand Archaeology Association (NZAA) Annual Conference
Venue: Club Mount Maunganui, Mount Maunganui, New Zealand
Date: 15 – 18 July
nzarchaeology.org/event/nzaa-annual- conference-2025

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