Analytical methods in shell midden analysis: discussing best-practice in modern archaeological methodology

Emmy Frost[1], Adam Magennis[2], Jillian Garvey[3], Amy Prendergast[4, 5], Matthew Meredith-Williams[1], Chloe Stringer[4] and Rebekah Kurpiel[1]

Abstract

Shell middens are places of spiritual, cultural, and archaeological importance, and are regularly recorded along our coastline and inland waterways. Traditionally, shell midden analyses focus on methods that are time-efficient but data-poor due to a combination of time pressure and large volumes of material. This typically results in only base-level information such as shell weights and higher-level taxon identification, meaning we often miss out on important details that middens can provide about how people were living on Country, and the important role of shellfish for First Peoples.

This paper will discuss and argue for the use of improved methods in the analysis of shell middens, including the Non-Repetitive Element (NRE) protocol for shell quantification, which will increase the accuracy of Minimum Number of Individuals (MNI) counts. Furthermore, the inclusion of palaeoenvironmental reconstruction methods (using proxies such as pollen, phytoliths, charcoal, and macrobotanicals) and geochemical analyses (such as sclerochronology) when analysing shell middens helps to formulate a stronger picture of the past environment, landscape history, and seasonality. Two new up-and-coming techniques are also discussed; thermo-microstratigraphic analysis, which can identify methods of cooking, and shell palaeoproteomics, which can identify mollusc species from their protein signatures.

Introduction

Shell middens are commonly found along coastal shorelines and inland waterways across what is now known as Victoria. These landscapes contain a vast number of Aboriginal shell middens, defined as accumulations of shell formed through cultural activities (Bowdler 2006; Claassen 1998; Waselkov 1987). The locations of these middens and their surrounding areas represent modified cultural landscapes, shaped and enhanced over time by the regular and adaptive presence of people on Country.

Each midden holds an important and irreplaceable record of people's lives along coasts, rivers, estuaries, and lakes. Despite the significant insights they offer into how people lived on Country—and their potential to reveal past environmental conditions—many shell middens are often analysed with efficiency as the primary goal, rather than with an emphasis on comprehensive data collection.

This paper will discuss current methodological innovations in archaeological and scientific analyses of shell midden material that can help generate information about people's activities on Country, and environmental conditions and the health of Country from deep time until present. By utilising these methodologies, we can improve the quality of analysis and provide much better information about the rich cultural heritage of our coastlines and inland waterways, which can help to reset, heal and care for Country.

In Victoria, there has been extensive research undertaken on many Aboriginal middens in the last 50 years. This includes (but is not limited to) studies at Moonlight Head on Gadubanud Country (Frankel 1998,1991), Glen Aire II on Gulidjan and Gadubanud Country (Fullegar 2011, Mulvaney 1962), Clinton Rocks, Point Hicks (Coutts & Witter 1977), and Nooramunga (Rogers et al. 2025) on Gunaikurnai Country, Discovery Bay (Godfrey 1984), Cape Duquesne (Richards 2012), and Cape Bridgewater (Lourandos 1983, 1997) on Gunditjmara Country. On Bunurong Country, there have been substantial archaeological surveys on the Mornington Peninsula (Sullivan 1981), and excavations at Stinker Bay (Gaughwin & Brennan 1986), Western Port Bay (Gaughwin and Sullivan 1984), Phillip Island (Gaughwin and Sullivan 1984), and Seal Point (Bowdler and Lourandos 1982, Lourandos 1980, 1983). Riverine middens along the Murray have also been investigated at Neds Corner (Garvey 2017, Prendergast et al. 2009) and in Yanga Nowie (Murray Sunset National Park) (Garvey 2017) on Ngintait, Latji Latji, and Nyeri Nyeri Country. Please refer to Hall and McNiven (1999) for further examples of Australian coastal archaeology.

There have also been a number of commercial

[1] Department of Archaeology and History, La Trobe University, Melbourne, Australia. <e.frost@latrobe.edu.au>

[2] Bunurong Land Council Aboriginal Corporation

[3] Monash Indigenous Studies Centre, Monash University, Clayton, VIC

[4] School of Geography, Earth and Atmospheric Sciences, University of Melbourne, Melbourne, Australia

[5] Australian Research Council Centre of Excellence for Indigenous and Environmental Histories and Futures, University of Melbourne, Melbourne, Australia

projects that have involved Victorian middens; however, confidentiality prevents specific reference here. Increasingly, we are "racing a rising tide" (Erlandson et al. 2008) to preserve information about sites along the coastline before they are lost, be it either from environmental influences such as sea level rise and erosion, or from human impact such as foot traffic, damage from vehicles, and civic and utility services infrastructure construction. Therefore, our professional responsibility should require us to complete our work to the highest standard possible by employing the most comprehensive and data-rich methodologies.

It is important to acknowledge that there are significant time pressures placed on many working archaeologists, and it is unrealistic to expect busy professionals to be completely familiar with all sub-specialties of archaeology. Archaeomalacology (the study of archaeological molluscan remains) is a relatively niche sub-specialty of archaeology, but one that often deals with tremendous quantities of material from a wide variety of marine, freshwater, lacustrine, and estuarine environments.

The identification, excavation, and analysis of shell middens can be complex, and the inclusion of midden specialists in the archaeological investigation of these sites is greatly beneficial. Aboriginal shell middens are highly diverse, and vary in their form, structure, positioning within the landscape, size, shape, purpose, function, distribution, and context. They are located in different types of coastal and inland landforms, where the formation of the deposit is influenced by the context of the landform and how people effectively and efficiently adapted to the landform. For example, the formation of a midden within a primary coastal dune along a beach system is created differently to a midden located on top of a sandstone coastal headland, and they both differ to a midden along a volcanic coastline where beaches are absent. Due to this diversity in size, scope, and distribution, a one-size-fits-all approach to shell midden analysis is not appropriate.

Typical Western studies of shell middens are concerned with the archaeological investigation of the shell, artefacts, bone, plant remains, and other organic materials. These generally follow prescribed scientific methodologies, and can inform how people interacted with Country, what past environmental and climatic conditions were like, and provide insight into diet and nutrition, shell use (cultural activity), modification (tools and equipment) and seasonality (Bowdler 2006, Claassen 1998, Coutts 1984, Coutts and Witter 1977).

Data obtained from these analyses are also useful in historical ecology, which uses environmental data from sites like shell middens to inform present-day land management (Rick 2023, Szabó 2015). Middens are ecological indicators and cultural markers. They are story points within the landscape, connection points across country and, on Bunurong Country, spiritual connection points to Whales and Dolphins. From perspectives through a lens of an ecological installation, coastal middens stabilise the caps of primary and secondary dune systems, creating rich organic soils, that contribute to soil nourishment processes of a dune ecosystem. Coastal shell middens serve as an example of conservation and biodiversity management approaches (Caring for Country), where soil nourishment processes from a midden contribute to seed bank regeneration and healthy habitats.

Currently, shell midden analysis is undergoing an exciting period of innovation and methodological advancement. However, many of these new developments have yet to work their way into conventional professional practice. For example, traditional midden faunal quantification methods used in many commercial analyses have not kept up with the quantification improvements (such as the Non-Repetitive Element (NRE) protocol) now common in specialist research analyses. Here, several innovative techniques that could reasonably be applied to commercial shell midden analyses will be outlined in addition to introducing a few exciting up-and-coming methods in the field.

It is important to note that the best way to understand how people were living on Country in the past is by working in collaboration with Elders and communities and ensuring that research is co-designed and co-led. This enables Traditional Ecological Knowledge (TEK) and cultural knowledge to be incorporated (Tutchener et al. 2021; Garvey and Blake 2024; Gibbs et al. 2024) into archaeological analyses and interpretations. Furthermore, none of the Western scientific methods discussed here can provide information about the cultural values or spiritual significance of these sites. Shell middens are not just places of study and research for archaeologists, they are also "places of meaning, memory making, and identity for Indigenous communities" (Rick 2024).

Coastal shells middens are one of many cultural elements of a cultural landscape and need to be considered in the context of all of Country.

Excavation, dating, and sieve size

Although the primary focus of this paper is post-excavation laboratory processing techniques, a crucial component when analysing a shell midden is considering excavation methodology and sampling procedures. This will be discussed very briefly here, but for a comprehensive overview please see Bowdler (2006). Shell middens are often sites of such expanse and quantity of material that sampling needs to be very carefully considered, as it is usually neither possible nor desirable (especially as preservation, rather than wide-spread destruction of cultural heritage, is ideal) to excavate an entire midden. Bowdler (2006) discusses several options aside from whole-site excavation, one being long, continuous trenches sectioning the site, collecting solid (unsieved) samples in each excavated spit or unit, and/or collecting regularly spaced column samples post-excavation (Bowdler 2006, Claassen 1998). Ideally, there will at least be a series of unsieved samples for processing in the laboratory. This makes it possible for methods such as flotation to collect charcoal and macrobotanicals to occur.

When sieving shell midden material, sieve size bias must be considered. A large sieve fraction is unlikely to retain delicate taxa such as rodents, small fish, or birds (Nagaoka 2005, Muckle 1994, Vale and Gargett 2002). While very small sieve sizes (1mm) may not retain substantial material identifiable to species (as identified by Vale and Gargett (2002) in their experimental study on fish-bone retention), it is important to retain if recording shell by weight as small fragments can contribute to the overall weight (Muckle 1994).

Analytical units

Determining the analytical units for the midden sequence is also crucial for understanding rates of change over time. Analytical units can be derived from cultural stratigraphy, natural stratigraphy, or during later analysis, and both structure the data and predetermine explanations by drawing artificial boundaries to the data (Frankel 1988). Frankel (1988) identified two main approaches to defining assemblages, firstly, using external features such as soil matrices, arbitrary excavation units such as spits, or stratigraphic features. The second looks at the features of artefacts (such as stone tool typology) to determine the unit. The size of the analytical unit is also important, as small units may provide finer-resolution data, but may also smooth the curve of change to the point where it looks artificially gradual. Conversely, large units may not accurately capture small variations over time. Analytical units are important, but can be complex to formulate, and further reading can be found in Frankel (1988).

Dating

Dating is another important consideration, and the Marine Reservoir Effect (MRE) has a significant impact on the way we must calibrate radiocarbon dates from marine sources. Marine samples can exhibit much older dates than contemporaneous terrestrial samples due to differing levels of carbon-14 (14C) in the marine and terrestrial environment (Ulm 2006, Ulm et al. 2023). Whilst 14C is evenly distributed throughout the terrestrial atmospheric reservoir and produced at a rapid pace, 14C in the deep sea often resides at great depths for long periods of time, and mixes unevenly with surface waters via upwelling (Ulm at al. 2023). The magnitude of the mixing of deep waters upward with surface waters depends on latitude, coastline shape, local climate and wind, trade winds, and ocean bottom topography, resulting in spatial variability across different coastlines. As a result, the time value we need to correct for is known as the ΔR value.

In the past, Gillespie's (1975; Gillespie and Temple 1977; Gillespie and Polach 1979) early work established a set of ΔR values by dating of six marine shell specimens from four areas around the Australian coast. This work found little variability in MRE, and following recommendation from Gillespie and Polach (1979), shell dates were generally corrected by subtracting 450 ± 35 14C years.

Currently, we have much larger datasets available, and the Australian ΔR Calculator (https://delta-r-calc.jcu.io) can provide the appropriate ΔR value for Australian coasts (where data exists).

For further information, please refer to Ulm et al. 2023 for a comprehensive overview.

Additionally, there has been some research into riverine/lacustrine reservoir effects near the Willandra Lakes (Gillespie et al 2009), however, results so far seem to indicate that a much smaller correction value (between +100±16 to −34±27 years) is needed, and is not likely to greatly affect Late Pleistocene dates in that region. However, further research in varying riverine and lacustrine environments is needed.

The location to finding an early date of a coastal shell midden on an elevated bluff or headland is the furthest point at the tip of the bluff or headland. Over time, the midden deposit extends both directions from the tip of the bluff or headland along the cliff tops, so dating should be taken at intervals from the tip in both directions. Middens would generally extend 20m back from the cliff face, even further and would generally interface with a walking track. These areas along the cliff tops were essentially coastal gardens beds, soil mounds and compost heaps contributing to soil stability, plant health and soil nourishment processes.

Improvements in shell identification, taxonomy, and nomenclature in official documentation

Generally, the first step in shell midden analysis (after the excavation, cleaning, and sieving of the material) is determining the taxon of mollusc, where possible, for each shell fragment. Identifying shell taxon can investigate as to whether there are any specific preferences in the types of mollusc collected, if taxa selection changes over time, and generally provide information about diet and lifestyle along waterways. Taxonomic identification of archaeological shell provides important information besides diet and subsistence, such as data on where the mollusc lived. Some species require a specific substrate type, water temperature, vegetation, amount of sun, and intensity of wave action to thrive. In addition, considerations such as the diet of the mollusc are important, as predatory and herbivorous molluscs have different behavioural patterns, could potentially present different nutritional profiles. Land snails are commonly used to reconstruct past environmental histories, as each species requires a specific micro-habitat with specific food, vegetation cover, moisture, shade levels, competitors, and predators (Evans 1972; Allen 2017). The presence of those certain species then informs about local environment, climate, shore type, vegetation, and water conditions. Subsequently, any change in in shell taxon may also indicate change in the palaeoenvironment.

There is room for significant improvement in the way that we identify and record shells and shell middens in Victoria. This is especially relevant when looking at official resources provided to Victorian archaeologists by governing bodies such as First Peoples-State Relations (FP-SR).

The Victorian Aboriginal Heritage Register (VAHR) shell midden component form and the FP-SR "Guide to Shells Commonly Found in Victorian Aboriginal Shell Middens" (hereafter referred to as the FP-SR Shell Guide) provide outdated and/or incorrect options for the taxonomic of the most common mollusc genera in Victoria (**Figure 1**) markings.

Shell Species List

Rocky Platform			
1. Turbo	9. Conus	16. Paphies	Freshwater
2. Cabestana	10. Nerita	17. Polinices	22. Velesunio
3. Abalone	11. Mytilus	18. Glycymeris	23. Alathyria
4. Austromytilus	12. Scutus	Estuarine	
5. Thais	Sandy Shore	19. Ostrea	24. Unknown
6. Chiton	13. Mactra	20. Anadara	
7. Limpet	14. Donax	21. Saccostrea	
8. Austrochonchlea	15. Katelysia		

Figure 1. Shell genus list available in the VAHR Shell Midden Aboriginal Place Component Form. Highlighted yellow are genera referred to with outdated names (Turbo> Lunella, Thais>Dicathais, Donax>Latona). Blue indicates common names, not scientific names. Red indicates a genus misspelled (likely meant to be Austrocochlea). (Image adapted from First Peoples-State Relations 2025)

In terms of the use of the FP-SR Shell Guide as a tool for species identification, the exclusive use of black and white illustrations and information from decades-old sources (MacPherson and Gabriel 1962, Beesley et al. 1998 and Smith and Kershaw 1979) instead of modern colour photography and contemporary species names has the potential to impede successful speciation. This is especially important as many shells, especially those from younger middens, will retain their identifiable coloured markings.

One of the most common species in south-eastern Australian shell middens serves as an example of the complicated taxonomy of molluscs in archaeological analyses. The Warrener (*Lunella undulata*) is often recorded as *Turbo undulatus* or *Turbo,* as it is identified as such in both the VAHR component form and the FP-SR Shell Guide. Due to a change in taxonomy, this name has not been the accepted species name since 2011 (**Table 1**).

If archaeologists are expected to provide up-to-date information on the ecology and environment of these species in site reports, the correct taxon must be used as the most recent malacological research will use these names. It is also important to maintain consistency and accuracy with scientific names to ensure that the species will be identifiable to a broad audience, as the correct scientific name will be used internationally. In contrast, common names are highly localised (**Table 2**) and can vary depending on language or community. The World Register of Marine Species (WoRMS) (https://www.marinespecies.org) is a useful online search tool that can provide the most up-to-date taxonomic information, even when searching for species names that are out of date by decades.

The VAHR component forms are also lacking when considering species diversity (Garvey and Perry 2015). For coastal middens, the lack of an option for the common *Diloma* top shells is likely due to *Austrocochlea* top shells being expected to represent all top shells. In freshwater environments, currently only the Southern River mussel (*Alathyria jacksoni*) and the Billabong mussel (*Velesunio ambiguus*) are available as options to record. Notably, freshwater gastropods such as the Barka or Darling River snail (*Notopala sublineata*) are not included as an option for freshwater midden species, despite evidence as to their dietary importance to people living in freshwater Country (Garvey 2017).

Previously, it was believed that *Notopala sublineata* snails were too small to be utilised as a food source and were present in middens only as by-catch (Walker 1996). However, this is at odds with archaeological research of the past decade (such as Garvey 2017), which found that people would have been deliberately targeting them, as the ecology of the snails shows that they live in a different part of the river system to the mussels. Even if these species did not yield a large amount of flesh, that flesh may have been especially delicious and/or nutritious.

Furthermore, not all molluscs are collected for dietary purposes. Shell can be utilised in a variety of ways, including but not limited to: medicinal practices where mussel shells were being used as phlebotomes (blood-letting knives) (A.A.C Le Souëf in Smythe vol. 1 1878: 296); fishhooks; adornment (Backhouse 1967, Labillière 1878, Jones 1965; Hook at al. 2024); cloak-making (Howitt 1904 741–742); tool-making (Weston

Name	Author	Status
Turbo undulatus	Lightfoot, 1786	Unaccepted
Turbo ludus	Gmelin, 1791	Unaccepted
Turbo anguis	Gmelin, 1791	Unaccepted
Turbo samson	Tenison-Woods, 1877	Unaccepted
Lunella (Subninella) undulata	Lightfoot, 1786	Alternate representation
Lunella undulata	Genus author: Röding, 1798 Species author: Lightfoot, 1786	Accepted as of 2011

Table 1. Changing taxonomy for Lunella undulata over the years (World Register of Marine Species 2025

Common name variants	Record
Bidharrun/Warrinha	Bunurong name
Periwinkle	Personal observation and conversations with Traditional Owners and archaeologists in Victoria and Tasmania
Warrener	
Wavy Periwinkle	Codes for Australian Aquatic Biota (CAAB)
Common Warrener	Atlas of Living Australia (ALA)
Lightning Moon	ALA
Common Warrener	Australian Faunal Directory (AFD)
Wavy Turban	AFD
Lightning Turban	AFD

Table 2. Common name variants for Lunella undulata

et al. 2017; Roberts et al. 2021); drinking vessels (Robinson 2008); making shell necklaces, and as an ingredient that contributes to making resin. Therefore, it is important that we record all molluscs that appear in middens, even if they do not seem to be significant economically.

As discussed previously, it is unreasonable for the average archaeologist to be an expert in every field, and only an archaeologist that specialises in faunal studies would have or need an exhaustive knowledge of the local fauna and flora for every given environment. Consequently, when species are omitted from reference material specifically designed to bridge that gap, it can lead to these animals going unrecognised as a product of cultural activities. This in turn leads to bias in the archaeological record (Garvey 2017).

Quantification: improving methodology and data accuracy

A key component of any archaeological midden analysis is quantifying (counting and measuring) the excavated shell. This is usually a substantial undertaking, as even a single 50 x 50 cm test pit can yield a large amount of shell midden material depending on the density and distribution of the deposit.

Contemporary professional analyses usually consider taxon (often not identified to species level), shell weight, shell condition (restricted to recording if the shell is visibly burnt), and occasionally the total number of fragments or Number of Identified Specimens (NISP). To quantify further, the Minimum Number of Individuals (MNI) may have been calculated by looking at left and right valves on a mussel and choosing the highest number, or by using complete gastropod shells or apices only for MNI. This typically results in only base-level information, meaning we often miss out on important details about diet, resource selection, economy, landscape use, and any change over time that middens can provide when we collect sufficient data concerning species identification, abundance, distribution, and habitat. This is crucial, as middens are important for understanding how people were living on Country and the important role of shellfish. Comparatively, a research-focused analysis may consider additional sets of data, such as shell size with multiple measurements, shape and structural properties of the shell, degree of preservation, as well as employing more detailed methods of quantifying MNI using multiple variables.

There have been long-standing debates about the use of MNI compared to weights in shell midden analyses. Early analyses considered only shell weight, as it was time- and cost-effective (Waselkov 1987). Mason et al. (1998) argue for weights to be discarded in favour of MNI as a standard, as weights alone assume horizontal midden homogeneity, ignore shell degradation, and are time consuming when sorting small fragments. Glassow (2000) stated that using MNI is insufficient, and that defining and identifying NRE in highly fragmented assemblages would be too difficult, so weights should be the preferred standard. Claassen (2000) suggested that no methodology is all-encompassing and argues for absolute frequencies (being abundance supplemented with non-shell values such as depositional rate, aerial extent of settlement, and quantities of artefacts). Therefore, a combination of techniques is the ideal way to approach a midden analysis.

There is a distinct difference in the amount of time a research analysis of a midden and a commercial analysis of a midden can devote to quantification. Here, a time-effective method of calculating MNI that can reduce the gap in data-richness between research and commercial data quality will be outlined.

To improve the accuracy of the MNI calculations, the Non-Repetitive Element (NRE) protocol following Harris, Weisler and Faulkner (2015) can be used. In this protocol, NRE are defined as a restricted range of diagnostic features that do not appear more than once per individual, such as the operculum associated with gastropods. Using multiple NRE for shell fragments increases the likelihood of accurately identifying species abundance within the assemblage as there is no reliance on one specific attribute to formulate species counts. Methods such as these have been used for many years when examining animal bone, but it is only in the last decade that expanding diagnostic criteria beyond simply one element (often the umbo in bivalves or apices in gastropods) has been considered. Kneppers (2024) found that when using Harris, Weisler, and Faulker's (2015) protocol, overall, there was a 3% increase in general MNI values, particularly in relation to Gastropoda.

Counting multiple NRE, instead of one part of the shell, improves the quality of our data. Preselecting an NRE that hypothetically would be the most abundant (i.e., the apex on a gastropod or left valve on a mussel) can underrepresent MNI as the selected NRE may not be the most consistently abundant or may return inaccurate MNIs of zero when the selected element is not present whilst other fragments are (Giovas 2009). To avoid this, all NRE should be counted, then that taxon should be quantified by selecting the most abundant NRE per sample, rather than restricting to one NRE. The difference in results obtained by using multiple NRE has been demonstrated as statistically significant when calculating MNI (Gutiérrez -Zugasti 2011).

Harris et al. (2015) found that calculating some NRE was time consuming and difficult while showing little MNI improvement, such as calculating bivalve adductor scars. These specific NRE could be dismissed, while retaining the NRE that provide more valuable data (such as gastropod NRE).

In terms of using these methods in commercial settings, once trained, selecting multiple NRE and sorting the shell accordingly is fast whilst simultaneously providing higher quality information- but it is up to both educators and working professionals to train graduates in these skills, and to ensure that these methods are employed in professional settings.

These newer methods are being taught in tertiary institutions where there are staff who are trained and specialise in this field. However, there are no standardised curriculum or resources available that outline the most appropriate methods. Furthermore, methods taught to students during their undergraduate studies will have little impact if graduates are unable to utilise them in professional settings.

Importantly, using improved MNI calculations will not affect comparability to previous studies, if NISP and weights are taken.

Improving data quality: reconstructing the palaeoenvironment

Shell midden analyses are not just focused on the shell material, but rather aim to unify analyses of the shell, stone, bone, plant remains, and other materials from the site in order to gain a more complete picture of the landscape and how people lived on Country in the past (Álvarez et al. 2011; Bailey 1975). Understanding the micro-organics of a midden deposit is still yet to be explored in many sites. One method to do this is by looking at multiple environmental proxies (preserved materials that can be analysed to infer past environmental conditions) to formulate high-resolution palaeoenvironmental records. These analyses have shown to be successful even in high-density shell matrices (Moss et al. 2019).

Palynology (pollen analysis) and phytolithology (phytolith analysis)

Palynology (the study of pollen) involves isolating and identifying plant pollen from sediment cores and using the proportions of different types of pollen present within the sample to ascertain what the local climate and vegetation would have been like in the past (Fægri and Iversen 1989; Moore et al. 1991). Pollen survives well in cool, dark, and anaerobic environments (Twiddle and Bunting 2010), and is particularly useful when looking at swamp or wetland environs.

Similarly, phytolithology looks at the micro-remains of silica bodies found in plant cell walls. However, phytoliths can survive acidic or aerobic conditions where other fossils like pollen are rarely preserved (Piperno 2006). Like pollen, phytolith analysis can provide valuable information about past vegetation and plant use. However, there is also a need for increased production of phytolith reference materials, as local reference collections for Australasian flora are incomplete (Turnbull et al. 2023).

Both of these methods are also useful for looking at human impacts on the landscape over time (Bakels 2020, Moss et al. 2019),), such as fire-burning events or targeted plant cultivation. A sediment core is preferred for sampling and can be collected with a hand-operated peat or 'Russian' corer, and the sample kept refrigerated until analysis.

To identify and enumerate the individual pollen grains or phytoliths in the sample, the desired botanical remain must be isolated from all other organic material in the sample. This technique requires a specialised laboratory, as each sample is treated with a series of chemical pretreatment steps to dissolve unwanted organics. The exact method and chemicals used varies according to the composition of the sediment and specific botanical remain targeted, but all methods require stringent safety precautions and protection from cross-contamination. Therefore, use of a dedicated laboratory is necessary. By identifying the vegetation present within the samples, we can ascertain what the terrestrial and aquatic vegetation would have looked like in the past, how it may have changed over time, and potentially examine subsistence and dietary habits. This is crucial for the overall understanding of a shell midden site, as their composition and location are dictated by environment.

Macrobotanicals

Macrobotanical studies involve examining the seeds, nuts, fruits, leaves, and other floristic parts of plants (excluding charcoal) found in archaeological soils (Carmichael 2019; Dilkes-Hall et al. 2019). By examining the non-woody remains of plants, which can be recovered from soil samples via flotation, we can determine which species of plant were present in the past, if species distribution had changed over time, and which species were likely to be of economic significance. This can then inform palaeoenvironment, history of plant use, diet, and seasonality (VanDerwarker and Peres 2010).

Anthracology (wood charcoal analysis)

Anthracology (wood charcoal analysis) provides information about past environments, subsistence strategies, land use, and management of Country by identifying the taxon of charcoal particles preserved in sediments (Crawford and Belcher 2014; Dotte-Sarout et al. 2015, King et al. 2022, Thomas et al. 2017). By identifying the species of wood macro-charcoal remains in shell middens, we can determine which plant species were used as fuel in hearths and identify land use patterns (seen in wood gathering patterns), and past fire regimes (such as cultural burns) (King et al. 2022).

In the field, soil samples are sufficient, and this method is suitable for fragments at least 2mm in size. To identify the species of wood, a high-powered microscope is required.

Geochemical studies

Geochemical analysis of shell to identify resource use and reconstruct coastal palaeoenvironments is a relatively common method (Canti 2017, García-Escárzaga et al. 2019, Godfrey 1994, King et al. 2025, Mannino and Thomas 2002; Prendergast et al. 2016; Prendergast and Schöne 2017; Prendergast et al. 2017) but are often under-utilised in commercial analyses due to the additional expense and time required. However, these methods are becoming increasingly affordable with techniques such as Laser Induced Breakdown Spectroscopy (LIBS) providing rapid and cost-effective screening methods.

Sclerochronology

To examine the palaeoenvironmental conditions and seasonality of shell middens, sclerochronology can be employed. Sclerochronology is defined as the study of physical and chemical variations in the accretionary hard parts of organisms and the temporal context in which they formed (Trofimova et al. 2020). Sclerochronology can estimate the ontogenetic ages (years relative to the age of the animal) of calcium carbonate ($CaCO_3$) accreting molluscs, as the shells of these animals grow in increments, like rings on a tree. Analysis of growth increments in the shell can tell us season of harvest, which in turn can tell us about seasonality of resource and site use (Prendergast et al. 2018; Alidoostsalimi et al. 2025).

These increments also contain biogeochemical signatures that relate directly to variations in the immediate environment. These can be analysed via stable oxygen isotope analysis, which uses the δ18O shell (oxygen isotope composition of shell carbonate) to reconstruct past environmental conditions. This is done by examining the isotopic composition of the shell, which varies according to the local water temperature and its isotopic composition (Kennett and Voorhies 1995). This technique can be used on both marine (Prendergast and Stevens 2014) and freshwater (Stringer and Prendergast 2023) species. Analysing the chemical compositions of the final growth portion of mollusc shells can also provide more accurate information of the seasonal harvesting of shellfish resources than analysing the growth increments alone (Alidoostsalimi et al. 2025). However, this method can be expensive, and the sample preparation and extraction time-consuming.

Diagenesis, which is the dissolution and recrystallization of carbonate in shells in response to taphonomic influences (such as depositional soil pH or thermal alteration via heating), can affect stable isotope and trace element values (Stringer and Prendergast 2023). To investigate the extent of the effect, screening is required and can incur additional expenses.

A new method, Laser Induced Breakdown Spectroscopy (LIBS), looks at shell biogeochemistry by using a short laser pulse to create a micro-plasma on the sample surface (Hausmann et al. 2023). This plasma emits light containing characteristic spectral lines which can be used to map the elemental composition of the sample. This can then be used to rapidly screen shell assemblages for variations in their temperature records over time. This technique is affordable, fast (requiring only a few seconds per sample to take measurements) and minimally invasive and with little sample prep required (King et al. 2025).

New techniques

Not all methodological innovations can be practicably used in contemporary commercial shell midden analyses. For example, to the authors' knowledge- no Australian laboratory is conducting shell palaeoproteomics or thermo-microstratigraphic studies for a commercial audience. These techniques are new, require further testing in Australian contexts, and have too few specialists able to conduct such studies on a broader scale. However, this may not always be the case, and as such these techniques are outlined here as an example of future potential in the discipline.

Thermal alteration of shell

When investigating the dietary contribution of shellfish, it is important to consider how these foods may have been prepared. Cooking allows tough plant foods and meats to be modified into easily digestible forms by rendering down fibrous or connective tissues to more palatable materials (Birch et al. 1986). However, depending on species, molluscs can be consumed both raw and cooked (Meehan 1977, Waselkov 1987). Often, the cooking of these foods is less concerned with breaking down muscle fibres to tenderise the flesh, but more about improving aroma, taste, texture, and adding warmth. Cooking can also assist with removing flesh from the shells, as it helps to open bivalves, and makes flesh removal easier from coiled gastropods by releasing the muscle attachment. Cooking of shellfish can also affect the nutritional properties of shellfish, namely the levels of trace elements and distribution of fatty acids (Frost 2023). In addition, roasting gastropods that contain toxins on very hot coals, clay balls, or other heat-retaining elements (such as rocks) could potentially reduce toxicity (such as the apex predator of an inter-tidal reef – the whelk which were targeted for eating and common in middens). Lawrence et al. (1994) found that cooking lobster *Homarus americanus* decreased the percentage of paralytic shellfish poisons present in the hepatopancreas by percentages ranging between 60-100%. Evidence of cooked molluscs in shell middens can be difficult to discern, as the presence of visibly burnt shells does not necessarily denote cooking. Mollusc shell can be thermally altered during other fire activities, such as by fires being lit on top of already-deposited shell beds (Simões and Aldeias 2022). Furthermore, many molluscs cook quickly over low temperatures (Frost 2023) and may not reach a high enough heat to visibly alter the exterior of the shell.

There are a variety of methods that look at thermal alteration of shell. Staudigel et al. (2019) argues that it is possible to distinguish boiling from roasting using carbonate clumped isotopes (Δ_{47}). Samples were found to have been heated up to 200°C and cooked unevenly, which is suggestive of roasting, rather than boiling, which would max at 100°C- a temperature that is not high enough to change the mineralogy of shell.

Another method is thermo-microstratigraphic analysis, which combines micromorphological analyses with microscopic Fourier transformed infrared (FTIR) spectroscopy to identify instances of in-situ fire events that are otherwise invisible macroscopically (Simões and Aldeias 2022). Specifically, this method looks at the thermal conversion of aragonite (one of the primary forms of shell calcium carbonate) into calcite. When applied to shell, this method aims to distinguish between cooking and burning of shell by examining mineralogical alterations caused by heat, as different temperatures cause different mineralogical changes. This is then combined with micromorphological analysis of archaeological thin sections to determine if the burning occurred pre-deposition or in-situ.

Another commonly employed method to detect thermal alteration in mollusc shells due to cooking or fire activity is Raman Spectroscopy. This method can be used to detect alteration of primary aragonite to calcite, which generally occurs in temperatures >300°C but may vary from species to species. In a study of the topshell *Phorcus turbinatus*, Milano et al. (2016; 2018) found that boiling had no effect on shell microstructure or geochemistry but once shells were heated >300°C, their microstructures began to change, and primary aragonite altered to calcite.

Shell palaeoproteomics

Shells in archaeological assemblages are often found highly fragmented, often to the point of being completely unidentifiable to species. If the main identifiable features of the shell such as the morphology and surface ornamentation are missing, it may be impossible to determine shell taxon macroscopically.

One potential solution is shell palaeoproteomics, dubbed 'palaeoshellomics' by Sakalauskaite et al. (2019). This method can identify otherwise completely indeterminable shell fragments by analysing the intracrystalline shell proteins and then characterising them using mass spectrometry techniques to create a 'molecular barcode' (Sakalauskaite et al. 2020, Alarashi et al. 2023). This 'molecular barcode' can then be used to identify the species of shell by comparing it to reference collections, provided relevant protein sequences of the candidate species are available.

While palaeoproteomics is a well-established technique for bone, it is less common in shell analyses. This is likely due to the small amount of protein in shell (over 300 times lower than in bone), as well as an overall limited understanding of shell protein sequences at this stage (Sakalauskaite et al. 2019). However, recent successful protein extraction by Sakalauskaite et al. (2020) on both modern and archaeological shell demonstrates that this method has potential.

This method will require testing on species local to south-eastern Australia, and there is some work that will be required before this technique is ready to use in any commercial application. Overall, this is an emergent technique but may become more prominent in the coming years.

Discussion and Conclusion

We have a professional responsibility to conduct our technical analyses to the highest possible standard within a reasonable and justifiable time frame. As it stands, the current recording, identification, and quantification methods for shell midden analysis are outdated. Fortunately, some methods (such as the Non-Repetitive Element protocol) outlined in this paper are simple improvements that can be easily implemented into modern commercial analyses with minor training and no additional field time, equipment or resources (**Table 3**). Others, such as palaeoenvironmental studies that involve sediment coring, specialist laboratory facilities, and/or additional time spent in the analysis stage, are more involved, and require additional planning and funding.

The additional information these analyses generate is vast, and if we are to maintain scientific rigour in our field then we must aim for best-practice. This will involve additional effort from archaeologists to disseminate up-to-date information, provide training opportunities to junior staff, and to ensure that there is appropriate time and funding allotted to employ up-to-date and data-rich methodologies.

Shell middens are of spiritual, social, cultural, and archaeological importance, and it is imperative that they are given the same quality of analyses as other sites. Unfortunately, as outlined in this paper, currently this is not the case due to a combination of a lack of knowledge and/or training opportunities, sub-standard recording and identification resources, and most crucially, substantial time pressures and large volumes of archaeological material.

There are efforts underway to update the official materials used for identifying and recording middens, which should also integrate Traditional Owner Knowledge Systems, still absent from Victorian Aboriginal Heritage Site Recording Cards (other than a section for Traditional Owner comments). We acknowledge that at the time of writing this, there is still a tremendous amount of potential data that is being missed, and there is a clear need for change. This paper has presented a variety of

	NRE	Pollen/ Phytoliths	Charcoal	Sclerochronology	Palaeoproteomics	Thermo-microstratigraphy
Additional field time		x	x	x		
Additional lab time	x	x	x	x	x	x
Specialised laboratory		x	x	x	x	x
Commercially available contractors	x	x	x	x		

Table 3. Requirements for each method in shell midden analysis outlined in this paper

potential methods to increase the data-richness of our analyses of shell middens. While some (such as shell palaeoproteomics and thermo-microstratigraphy) are still in the experimental stage, quantification methods such as the NRE protocol are simple to apply without any additional cost. By employing such methods, we can improve our analyses, produce higher-quality information about the rich cultural heritage of our coastlines and inland waterways, and try help heal and restore Country.

References

Alarashi, H., M. Benz, J. Gresky, A. Burkhardt, A. Fischer, L. Gourichon, M. Gerlitzki, M. Manfred, J. Sakalauskaite, B. Demarchi, M. Mackie, M. Collins, C.P. Odriozola, J.Á. Garrido Cordero, M.Á. Avilés, L. Vigorelli, A. Re, and H.G.K. Gebel 2023 Threads of memory: Reviving the ornament of a dead child at the Neolithic village of Ba`ja (Jordan). *PLOS ONE* 18(8).

Allen, M.J. 2017 *Molluscs in Archaeology: Methods, Approaches and Applications*. Oxford: Oxbow Books.

Alidoostsalimi, M., A.L. Prendergast, S. Ulm, R.N. Drysdale, J. Brown, R.M. Klaebe, and B. Dong 2025 Sclerochronology and oxygen isotope variations in modern Conomurex luhuanus shells: An archive for reconstructing palaeotemperature and shellfish gathering on the Great Barrier Reef, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 659:112633.

Álvarez, M., I. Briz Godino, A. Balbo, and M. Madella 2011 Shell middens as archives of past environments, human dispersal and specialized resource management. *Quaternary International* 239(1–2):1–7.

Backhouse, J. 1967 *A Narrative of a Visit to Australian Colonies*. New York: Johnson Reprint Corporation.

Bakels, C. 2020 Pollen and Archaeology In A. Henry (ed.), *Handbook for the Analysis of Micro-Particles in Archaeological Samples*, pp.203–224. Cham: Springer Nature.

Bailey, G.N. 1975 The role of molluscs in coastal economies: The results of midden analysis in Australia. *Journal of Archaeological Science* 2(1):45–62.

Beesley, P.L., G.J.B. Ross, & A. Wells (eds) 1998. *Mollusca: the southern synthesis.* Fauna of Australia 5. Melbourne: CSIRO Publishing.

Birch, H.E. and G. Schreiber 1986 Transcriptional regulation of plasma protein synthesis during inflammation. *The Journal of Biological Chemistry* 261(18):8077–8080.

Bowdler, S. 2006 Mollusks and Other Shells. In J. Balme, and A. Paterson (eds), *Archaeology in Practice: A Student Guide to Archaeological Analyses*. Pp. 316–314. Malden: Blackwell Publishing.

Bowdler, S. and H. Lourandos 1982 Both sides of the Bass Strait. In S. Bowdler (ed.) *Coastal Archaeology in Eastern Australia*, pp. 121–132. Department of Prehistory, Research School of Pacific Studies, Australian National University: Canberra.

Canti, M. 2017 Burnt carbonates In C. Nicosia and G Stoops (eds), *Archaeological Soil & Sediment Micromorphology*, pp.181–188 Hoboken: Wiley.

Carmichael, J. 2019 'Vegetable treasures': the archaeobotanical remains from the former Carlton and United Brewery Phase 2 excavations in Melbourne. *Excavations, Surveys and Heritage Management in Victoria.* 8:7–15.

Claassen, C. 1998 *Shells*. New York: Cambridge University Press.

Claassen, C. 2000 Quantifying Shell: Comments on Mason, Peterson, and Tiffany. *American Antiquity* 65(2):415–418.

Coutts, P.J. 1984 *Coastal Archaeology in South-Eastern Victoria.* Melbourne: Aboriginal Affairs Victoria.

Coutts, P.J. and D.V.A.S. Witter 1977 *A Guide to Recording Archaeological Sites in Victoria.* Melbourne: Aboriginal Affairs Victoria.

Crawford, A.J. and C.M. Belcher 2014 Charcoal morphometry for paleoecological analysis: The effects of fuel type and transportation on morphological parameters1. *Applications in Plant Sciences* 2(8).

Dilkes-Hall, I.E., S. O'Connor, and J. Balme 2019 People-plant interaction and economic botany over 47,000 years of occupation at Carpenter's Gap 1, south central Kimberley. *Australian Archaeology* 85(1):30–47.

Dotte-Sarout, E., X. Carah, and C. Byrne 2015 Not just carbon: assessment and prospects for the application of anthracology in Oceania. *Archaeology in Oceania* 50(1):1–22.

Erlandson, J.M., T.C. Rick, T.J. Braje, A. Steinberg, and R.L. Vellanoweth 2008 Human impacts on ancient shellfish: a 10,000 year record from San Miguel Island, California. *Journal of Archaeological Science* 35(8):2144–2152.

Evans, J.G. 1972 *Land Snails in Archaeology: With Special Reference to the British Isles*. London and New York: Seminar Press.

Faegri, K. and J. Iversen 1989 *Textbook of Pollen Analysis*. Oxford: Blackwell Scientific.

Frankel, D. 1988 Characterising Change in Prehistoric Sequences: A View from Australia. *Archaeology in Oceania* 23(2):41–48.

Frankel, D. 1991 *Remains to Be Seen: Archaeological Insights into Australian Prehistory*. South Melbourne: Longman Cheshire.

Frost, E. 2023 Pinmatik/Rocky Cape Revisited: Investigating Dietary Change at the Pinmatik/ Rocky Cape Caves, North-Western Lutruwita. Unpublished PhD thesis, Department of Archaeology and History, La Trobe University, Bundoora.

Fullagar, R. 2011 Changing Perspectives in Australian Archaeology, part VIII. Burins, bones and base camps: a re-analysis of Aire Shelter 2, Glenaire, southern Victoria. *Technical Reports of the Australian Museum (online)* 23(8):103–131.

García-Escárzaga, A., I. Gutiérrez-Zugasti, A. Cobo, D. Cuenca-Solana, J. Martín-Chivelet, P. Roberts, and M.R. González-Morales 2019 Stable oxygen isotope analysis of Phorcus lineatus (da Costa, 1778) as a proxy for foraging seasonality during the Mesolithic in northern Iberia. *Archaeological and Anthropological Sciences* 11(10):5631–5644.

Garvey, J. 2017 Australian Aboriginal freshwater shell middens from late Quaternary northwest Victoria: Prey choice, economic variability and exploitation. *Quaternary International* 427:85–102.

Garvey, J. and D. Perry 2015 Lessons from freshwater middens: Archaeological and Traditional Owner perspectives of the importance of these cultural sites from the Central Murray River Valley, northwest Victoria. *Excavations, Surveys and Heritage Management in Victoria* 4:39–24.

Garvey, J. and K.A. Blake 2024 Koling wada ngal (let's walk together): Reimagining Australian archaeology through the weaving together of Traditional Ecological Knowledge (TEK) and academic colonialism. *Australian Archaeology* 90(1):36–38.

Gaughwin, D. and G. Brennan 1986 Stinker Bay Shell Midden. *Archaeology in Oceania* 21(1):63–68.

Gaughwin, D. and H. Sullivan 1984 Aboriginal boundaries and movements in Western Port, Victoria. *Aboriginal history* 8(1/ 2):80–98.

Gibbs, M.C., L.M. Parker, E. Scanes, and P.M. Ross 2024 Recognising the importance of shellfish to First Nations peoples, Indigenous and Traditional Ecological Knowledge in aquaculture and coastal management in Australia. *Marine and Freshwater Research* 75(4) MF23193.

Giovas, C.M. 2009 The shell game: analytic problems in archaeological mollusc quantification. *Journal of Archaeological Science* 36(7):1557–1564.

Gillespie, R 1975 The Suitability of Marine Shells for Radiocarbon Dating. Unpublished PhD thesis, University of Sydney, Sydney.

Gillespie, R. and H.A. Polach 1979 The suitability of marine shells for radiocarbon dating of Australian prehistory. In R. Berger and H. Suess (eds), *Proceedings of the Ninth International Conference on Radiocarbon Dating*, pp.404–421. Los Angeles: University of California Press.

Gillespie, R. and R.B. Temple 1977 Radiocarbon dating of shell middens. *Archaeology and Physical Anthropology in Oceania* 12:26–37.

Gillespie, R., D. Fink, F. Petchey, and G. Jacobsen 2009 Murray-Darling basin freshwater shells: riverine reservoir effect. *Archaeology in Oceania* 44(2):107–111.

Glassow, M.A. 2000 Weighing vs. Counting Shellfish Remains: A Comment on Mason, Peterson, and Tiffany. *American Antiquity* 65(2):407–414.

Godfrey, M.C.S 1994 The Archaeology of the Invisible: Seasonality and Shellfishing at Discovery Bay, Victoria: The Application of Oxygen Isotope Analysis. Unpublished PhD thesis, School of Chemistry, La Trobe University, Bundoora.

Godfrey, M.C.S. 1984 Seasonality and Shellfishing at Discovery Bay, Victoria. Unpublished Masters thesis, Division of Prehistory, La Trobe University, Bundoora.

Gutiérrez Zugasti, F.I. 2011 Shell Fragmentation as a Tool for Quantification and Identification of Taphonomic Processes in Archaeomalacological Analysis: The Case of the Cantabrian Region (northern Spain). *Archaeometry* 53(3):614–630.

Hall, H.J and I.J McNiven (eds) 1999 *Australian Coastal Archaeology*. Canberra: ANH Publications.

Harris, M., M. Weisler, and P. Faulkner 2015 A refined protocol for calculating MNI in archaeological molluscan shell assemblages: a Marshall Islands case study. *Journal of Archaeological Science* 57:168–179.

Hausmann, N., D. Theodoraki, V. Piñon, P. Siozos, A. Lemonis, and D. Anglos 2023 Applying laser induced breakdown spectroscopy (LIBS) and elemental imaging on marine shells for archaeological and environmental research. *Scientific Reports* 13(1):19812.

Hook, F., M.C. Langley, S. Ulm, J. McDonald, and P. Veth 2024 Late Pleistocene scaphopod beads from Boodie Cave and deep time traditions of personal ornamentation in northwest Australia. *Australian Archaeology* 90(3):280–298.

Howitt, A.W 1904 *The Native Tribes of South-East Australia,* London: Macmillan.

Jerardino, A., P. Faulkner, and C. Flores 2017 Current methodological issues in archaeomalacological studies. *Quaternary International* 427:1–4.

Jones, R. 1965 Archæological Reconnaissance in Tasmania, Summer 1963/1964. *Oceania* 35(3):191–201.

Kennett, D. and B. Voorhies 1995 Middle Holocene Periodicities in Rainfall Inferred from Oxygen and Carbon Isotopic Fluctuations in Prehistoric Tropical Estuarine Mollusc Shells. *Archaeometry* 37(1):157–170.

King, F., G. Stannard, and R. Kurpiel 2022 Charcoal Analysis: What Can We Learn from Anthracology and Other Methods? *Excavations, Surveys and Heritage Management in Victoria* 11:119–126.

King, F., A.L. Prendergast, E. Frost, G. Stannard, J. Garvey, R. Cosgrove, R.N. Drysdale, and N. Hausmann 2025 A key to seasonal shellfish exploitation: Elemental mapping of Mg/Ca ratios in Lutruwita (Tasmania) Cellana limpets. *Palaeogeography, Palaeoclimatology, Palaeoecology* 674:113023.

Kneppers, M.C., A.B.J. Lambrides, M. Litster, S. Ulm, I.J. McNiven, M. Harris, and C. Maclaurin 2024 Beyond hinges and spires: A critical examination of archaeomalacological quantification methodologies using coral reef molluscan assemblages from Jiigurru (Lizard Island Group), northern Great Barrier Reef. *Australian Archaeology* 90(3):299–318.

Labilliere, F.P. 1878. *Early History of The Colony of Victoria volume 2: From Its Discovery to Its Establishment as a Self-Governing Province of the British Empire.* London: Sampson, Low, Marston, Searle, and Rivington.

Lawrence, J.F., M. Maher, and W. Watson-Wright 1994 Effect of cooking on the concentration of toxins associated with paralytic shellfish poison in lobster hepatopancreas. *Toxicon* 32(1):57–64.

Le Souëf, A.A.C 1978 Notes on the natives of Australia. In R.B Smyth (ed.) *The Aborigines of Victoria; with Notes Relating to the Habits of the Natives of Other Parts of Victoria and Tasmania,* pp. 289–299, Melbourne: Government Printer.

Lourandos, H. 1980 Change or stability?: Hydraulics, hunter-gatherers and population in temperate Australia. *World Archaeology* 11(3):245–264.

Lourandos, H. 1983 Intensification: A Late Pleistocene-Holocene Archaeological Sequence from Southwestern Victoria. *Archaeology in Oceania* 18(2,):81–94.

Lourandos, H. 1997 *Continent of Hunter-Gatherers: New Perspectives in Australian Prehistory*. New York: Cambridge University Press.

MacPherson, J.H. and Gabriel C. J. 1962 *Marine Molluscs of Victoria*. Parkville, Melbourne University Press.

Mannino, M.A. and K.D. Thomas 2002 Depletion of a resource? The impact of prehistoric human foraging on intertidal mollusc communities and its significance for human settlement, mobility and dispersal. *World Archaeology* 33(3):452–474.

Mason, R.D., M.L. Peterson, and J.A. Tiffany 1998 Weighing vs. Counting: Measurement Reliability and the California School of Midden Analysis. *American Antiquity* 63(2):303–324.

Meehan, B. 1977 Hunters by the seashore. *Journal of Human Evolution* 6(4): 363-370.

Milano, S., S. Lindauer, A.L. Prendergast, E.A. Hill, C.O. Hunt, G. Barker, and B.R. Schöne 2018 Mollusk carbonate thermal behaviour and its implications in understanding prehistoric fire events in shell middens. *Journal of Archaeological Science: Reports* 20:443–457.

Milano, S., A.L. Prendergast, and B.R. Schöne 2016 Effects of cooking on mollusk shell structure and chemistry: Implications for archeology and paleoenvironmental reconstruction. *Journal of Archaeological Science: Reports* 7:14–26.

Moore, P.D., J.A. Webb, and M.E. Collinson 1991 *Pollen Analysis.* 2nd ed. Oxford: Blackwell Science.

Moss, P.T., S. Ulm, L. Mackenzie, L.A. Wallis, D. Rosendahl, and L. Steinberger 2019 Robust local vegetation records from dense archaeological shell matrixes: a palynological analysis of the Thundiy shell deposit, Bentinck Island, Gulf of Carpentaria, Australia. *Archaeological and Anthropological Sciences* 11(2):511–520.

Muckle, R.J. 1994 Differential recovery of mollusk shell from archaeological sites. *Journal of Field Archaeology* 21(1):129–131.

Mulvaney, D.J 1962. Archaeological excavations on the Aire River, Otway Peninsula, Victoria. *Proceedings* *of the Royal Society of Victoria* 75:1–15

Nagaoka, L. 2005 Differential recovery of Pacific Island fish remains. *Journal of Archaeological Science* 32(6):941–955.

Piperno, D.R. 2006 *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists*. Lanham, MD: AltaMira Press.

Prendergast, A. L., Bowler, J. M., and Cupper, M. L. 2009. Late Quaternary Environments and Human Occupation in the Murray River Velley of Northwestern Victoria. In Fairbairn, A., O'Connor, Sr. and Marwick, B. *New Directions in Archaeological Science*. Terra Australis, 28:55–74.

Prendergast, A.L., A.J.E. Pryor, H. Reade, and R.E. Stevens 2018 Seasonal records of palaeoenvironmental change and resource use from archaeological assemblages. *Journal of Archaeological Science: Reports* 21:1191–1197.

Prendergast, A.L and R.E Stevens 2014 Molluscs (Isotopes): Analyses in Environmental Archaeology. In C Smith (ed.), *Encyclopedia of Global Archaeology*, pp. 5010–5019. New York: Springer.

Prendergast, A.L., R.E. Stevens, T.C. O'Connell, A. Fadlalak, M. Touati, A. al-Mzeine, B.R. Schöne, C.O. Hunt, and G. Barker 2016 Changing patterns of eastern Mediterranean shellfish exploitation in the Late Glacial and Early Holocene: Oxygen isotope evidence from gastropod in Epipaleolithic to Neolithic human occupation layers at the Haua Fteah cave, Libya. *Quaternary International* 407:80–93.

Prendergast, A.L. and B.R. Schöne 2017 Oxygen isotopes from limpet shells: Implications for palaeothermometry and seasonal shellfish foraging studies in the Mediterranean. *Palaeogeography, Palaeoclimatology, Palaeoecology* 484:33–47.

Prendergast, A.L., E.A.A. Versteegh, and B.R. Schöne 2017 New research on the development of high-resolution palaeoenvironmental proxies from geochemical properties of biogenic carbonates. *Palaeogeography, Palaeoclimatology, Palaeoecology* 484:1–6.

Richards, T. 2012 An early-Holocene aboriginal coastal landscape at Cape Duquesne, southwest Victoria, Australia. In S.G Heberle & B. David (eds) *Peopled Landscapes: Archaeological and Biogeographic Approaches to Landscapes,* pp.65–102. Canberra: ANU Press.

Rick, T.C. 2023 Coastal Archaeology and Historical Ecology for a Changing Planet. *Journal of Anthropological Research* 79(2):153–175.

Rick, T.C. 2024 Shell Midden Archaeology: Current Trends and Future Directions. *Journal of Archaeological Research* 32(3):309–366.

Roberts, A., C. Westell, C. Wilson, M.C. Langley, River Murray And Mallee Aboriginal Corporation, Ngarrindjeri Aboriginal Corporation 2021 Aboriginal serrated and perforated shell artefacts from the Murray River, South Australia. *Archaeology in Oceania* 57(1):16–27.

Robinson, G.A. 2008 *Friendly Mission: The Tasmanian Journals and Papers of George Augustus Robinson*. (N. J. B. Plomley, ed.). Second edition. Hobart, Tasmania: Queen Victoria Museum and Art Gallery and Quintus Publishing, University of Tasmania.

Rogers, A.J., D.M. Kennedy, B. David, R. Mullett, J. Fresløv, F. Petchey, L.J. Arnold, M. Demuro, GunaiKurnai Land and Waters Aboriginal Corporation, C. Drayton, and H. Mullett 2025 Adapting to rapidly transforming seascapes in the Mid- to Late Holocene, southeastern Australia. *Frontiers in Environmental Archaeology* 4:1548062.

Sakalauskaite, J., S.H. Andersen, P. Biagi, M.A. Borrello, T. Cocquerez, A.C. Colonese, F. Dal Bello, A. Girod, M. Heumüller, H. Koon, G. Mandili, C. Medana, K.E. Penkman, L. Plasseraud, H. Schlichtherle, S. Taylor, C. Tokarski, J. Thomas, J. Wilson, F. Marin, and B. Demarchi 2019 'Palaeoshellomics' reveals the use of freshwater mother-of-pearl in prehistory. *eLife* 8:e45644.

Sakalauskaite, J., F. Marin, B. Pergolizzi, and B. Demarchi 2020 Shell palaeoproteomics: First application of peptide mass fingerprinting for the rapid identification of mollusc shells in archaeology. *Journal of Proteomics* 227:103920.

Simões, C.D. and V. Aldeias 2022 Thermo-microstratigraphy of shells reveals invisible fire use and possible cooking in the archaeological record. *Frontiers in Earth Science* 10:869487

Smith, B.J. & R. C. Kershaw. 1979. *Field guide to the non-marine molluscs of southeastern Australia.* Canberra: ANU Press.

Staudigel, P.T., P.K. Swart, A. Pourmand, C.A. Laguer-Díaz, and W.J. Pestle 2019 Boiled or roasted? Bivalve cooking methods of early Puerto Ricans elucidated using clumped isotopes. *Science Advances* 5(11):eaaw5447.

Stringer, C.A. and A.L. Prendergast 2023 Freshwater mollusc sclerochronology: Trends, challenges, and future directions. *Earth-Science Reviews* 247:104621.

Sullivan, H. 1981 *Archaeological Survey of the Mornington Peninsula, Victoria,* Melbourne: Aboriginal Affairs Victoria.

Szabó, P. 2015 Historical ecology: past, present and future. *Biological reviews of the Cambridge Philosophical Society* 90(4):997–1014.

Thomas, K.D. and M.A. Mannino 2017 Making numbers count: Beyond minimum numbers of individuals (MNI) for the quantification of mollusc assemblages from shell matrix sites. *Quaternary International* 427:47–58.

Trofimova, T., S.J. Alexandroff, M.J. Mette, E. Tray, P.G. Butler, S.E. Campana, E.M. Harper, A.L.A. Johnson, J.R. Morrongiello, M. Peharda, B.R. Schöne, C. Andersson, C.F.T. Andrus, B.A. Black, M. Burchell, M.L. Carroll, K.L. DeLong, B.M. Gillanders, P. Grønkjær, D. Killam, A.L. Prendergast, D.J. Reynolds, J.D. Scourse, K. Shirai, J. Thébault, C. Trueman, and N. de Winter 2020 Fundamental questions and applications of sclerochronology: Community-defined research priorities. *Estuarine, Coastal and Shelf Science* 245:106977.

Turnbull, M., A.G. Parker, and N.R. Jankowski 2023 The history of phytolith research in Australasian archaeology and palaeoecology. *Vegetation History and Archaeobotany* 32(6):655–677.

Tutchener, D. and R. Kurpiel 2021 Proximity of Aboriginal Cultural Heritage Places to Fresh and Salt Water in the Bunurong Land Council Aboriginal Corporation Registered Aboriginal Party Area: Preliminary GIS Analysis. *Excavations, Surveys and Heritage Management in Victoria* 10:47–51.

Twiddle, C.L. and M.J. Bunting 2010 Experimental investigations into the preservation of pollen grains: A pilot study of four pollen types. *Review of Palaeobotany and Palynology* 162(4):621–630.

Ulm, S. 2006 Australian Marine Reservoir Effects: A Guide to ΔR Values. *Australian Archaeology* 63(1):57–60.

Ulm, S., D. O'Grady, F. Petchey, Q. Hua, G. Jacobsen, L. Linnenlucke, B. David, D. Rosendahl, M.M.E. Bunbury, M.I. Bird, and P.J. Reimer 2023 Australian marine radiocarbon reservoir effects: δr atlas and δr calculator for Australian mainland coasts and near-shore islands. *Radiocarbon* 65(5):1139–1159.

Vale, D. and R.H. Gargett 2002 Size Matters: 3-mm Sieves Do Not Increase Richness in a Fishbone Assemblage from Arrawarra I, an Aboriginal Australian Shell Midden on the Mid-north Coast of New South Wales, Australia. *Journal of Archaeological Science* 29(1):57–63.

VanDerwarker, A.M. and T.M. Peres, editors 2010 *Integrating Zooarchaeology and Paleoethnobotany*. New York, NY: Springer New York.

Walker, K. 1996 The River Snail Notopala hanleyi: An Endangered Pest. *Xanthopus (Nature Conservation Society of SA)* 1–5.

Waselkov, G. 1987 Shellfish Gathering and Shell Midden Archaeology. *Advances in archaeological method and theory* 10:93–210.

Weston, E., K. Szabó, and N. Stern 2017 Pleistocene shell tools from Lake Mungo lunette, Australia: Identification and interpretation drawing on experimental archaeology. *Quaternary International* 427:229–242.

WoRMS - World Register of Marine Species - Lunella undulata (Lightfoot, 1786) 2012 November 12. Retrieved 16 April 2025 < https://web.archive.org/web/20121112030143/http://www.marinespecies.org/aphia.php?p=taxdetails&id=579271 >.