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Macropods and measurables: A critical review of contemporary isotopic approaches to palaeo-environmental reconstructions in Australian zooarchaeology

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ABSTRACT

Stable isotopic analyses of herbivorous mammal remains are a powerful and globally applied tool for reconstructing past environments and ecological histories from archaeological sites. For Australia, a substantial corpus of foundational literature has competently established the environmental sources of isotopic variation in modern kangaroo and wallaby species. However, despite the pervasive distribution of these kinds of macropods in contemporary and archaeological contexts, isotopic techniques are utilised infrequently. Our review of the history of macropod isotopic analysis identifies and proposes solutions to the complexities that have inhibited its widespread application in Australian archaeology. This includes a description of relevant basic principles including ecology, physiology and isotopic fractionation. To support our claims for the considerable research potential of macropod remains, we present preliminary analyses of tooth enamel carbonates from archaeological deposits at Boodie Cave, Barrow Island, located in Australia's northwest arid zone.

1. Introduction

Archaeological evidence from the late Quaternary landscapes of Australia reveals that hunter-gatherer populations inhabited a continent characterised by highly variable environments impacted by dramatic transformations in climate. Climatic change was magnified in the arid coastal environments of northwest Australia by fluctuating sea levels, irregular precipitation, and actively evolving marine and terrestrial ecosystems. Therefore, a critical concern for archaeologists is to investigate the potential interactions between these environmental vectors and human behavioural adaptations through the detailed reconstruction of ecological histories.

While archaeologists have traditionally inferred palaeo-environments in Australia from various remote or regional data sources (e.g. Denniston et al., 2013; Fitzsimmons et al., 2013; Williams et al., 2015), more recently they have sought to identify and exploit proximal archaeological evidence capable of producing detailed local climate records (e.g. Brockwell et al., 2013; Byrne et al., 2013; Disspain et al., 2011; Twaddle et al., 2016). Macropods belong to the family Macropodidae which consists of kangaroos, wallabies and their smaller relatives (Strahan, 1995). Isotopic studies of extant macropod populations in Australia have highlighted the potential for kangaroo and wallaby remains to contribute valuable local palaeo-environmental data to archaeological inquiries by adeptly identifying the essential relationships between isotopic variability and ecological change (e.g. Fraser, 2005; Murphy, 2006; Murphy et al., 2007a; Murphy et al., 2007b). However, Australian archaeological applications have been limited to the investigation of late Holocene climatic change on macropod bone collagen from Tungawa (also referred to as Fromms Landing) in South Australia (Roberts and Pate, 1999). Such limited application can be attributed to complexities associated with sampling and the improbability of recovering well-preserved organic material such as bone collagen; particularly in pre-Holocene contexts (Pate, 1997, 1998).

This review considers the usefulness, accuracy and feasibility of conducting isotopic studies on macropod bone and tooth enamel given their presence as ubiquitous features in the archaeological record. Isotope research and the fundamental principles that underpin its application are critically examined to determine its relevance and capacity to add value to Australian archaeological research. The potential for isotopic analysis to reconstruct palaeo-seasonality will also be considered. In order to more closely address practical challenges identified in this review, results from a pilot study testing the value of macropod enamel carbonates for Pleistocene specimens is presented. These specimens were recovered from archaeological deposits in

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Boodie Cave on Barrow Island in Australia's northwest. Importantly, enamel (a robust and largely non-porous inorganic material) is less sensitive to taphonomic impacts and thus represents a significant but previously un-utilised alternative to collagen based analyses.

2. Stable isotope ecology: fundamentals and relationships

Applications of stable isotopic analyses in the global archaeological literature are manifest. For example, human remains are routinely studied to examine palaeodiet, past environments and mobility (e.g. Gil et al., 2011; Katzenberg, 2000; Pate, 2008; Stantis et al., 2015). Similarly, zooarchaeological isotope studies include regular investigations of exchange, seasonality, animal diet, ecosystems and herding strategies (e.g. Arnold et al., 2013; Eerkens et al., 2013; Fisher and Valentine, 2013; Fraser et al., 2008; Skrzypek et al., 2011). Furthermore, these zooarchaeological applications have been the subject of multiple critical reviews (e.g. Clementz, 2012; Koch, 2007). While the concept and practice of using animal remains for investigations of past ecological relationships is well-established, three challenges still define the field. The first challenge is practical and relates to the degree of preservation required for meaningful results. The second challenge is methodological and relates to the complexities inherent in ensuring sufficient taphonomic, ecological, physiological, and osteological information for each sampled taxa is factored into investigations to ensure the interpretation of isotopic results is accurate (Pilaar Birch, 2013). The final challenge is interpretative and relates to the difficulty in adequately integrating isotopic data with the potentially voluminous information obtained from multidisciplinary inquiries of complex archaeological assemblages containing botanics, lithics, fauna and shell. In this review we will focus on generating solutions for practical and methodological complexities as they relate to macropod remains.

The early prospective study of macropod collagen from archaeological assemblages (Roberts and Pate, 1999) has addressed some of these complexities. However, an increased focus on macropods in the fields of isotopic ecology and palaeontology suggest that the potential for archaeological applications should be further investigated (e.g. Forbes et al., 2010; Murphy, 2006; Murphy and Bowman, 2006; Prideaux et al., 2007; Pate and Anson, 2008; Witt and Ayliffe, 2001). In particular, the application of isotopic studies to non-organic macropod remains (including tooth enamel carbonates) should be explored as a previously unapplied but high potential complement to collagen research. The following short description of key isotopic principles provides the necessary context for the review of prior literature and its implications for archaeologists interested in detailed analyses of macropod remains.

2.1. Stable isotopes: natural abundance variation, fractionation and notation

Isotopes are forms of the same element but differ in the number of neutrons contained in the nucleus and, therefore, also differ in weight. Stable isotopes are those isotopes that do not undergo radioactive decay. For many common elements, including oxygen, carbon and nitrogen, the lighter stable isotope is far more abundant in the biosphere resulting in a heavily skewed distribution (Ben-David and Flaherty, 2012). The marginal variation in weight between stable isotopes of the same element creates subtle chemical differences that influence the cycling and distribution of isotopes in the biosphere via processes referred to as mixing and fractionation (Fry, 2006). This means that isotopes can function as tracers to track modern and ancient ecological conditions. Using this as an empirical tracer-based approach is particularly relevant for archaeological inquiries where alternative methods of ecological study, including direct observations and measurements, are not possible (Clementz, 2012). In general, isotopic values are given in per mil (‰) difference in the ratio of heavier to lighter isotopes (R) compared to that of a standard and are expressed using the standard delta notion (δ) as follows: $\delta = [(R_{sample} / R_{standard} - 1)] \times 1000$ (Fry, 2006).

2.2. Macropod physiology and feeding ecology

Macropods are a particularly high potential candidate for applying isotopes analyses to trace ecological relationships due to particulars concerning their distribution, physiology and feeding ecology. Within the family Macropodidae there are forty-five species of kangaroos and wallabies that occur only in Australia (Jackson, 2003; Jackson and Groves, 2015). They occupy highly variable habitats, from arid deserts to tropical forests, and vary greatly in size from a few hundred grams up to 90 kg (Strahan, 1995; Taylor, 1984). Together these diverse animals represent the most ubiquitous, iconic and recognisable of the Australian marsupials.

In herbivorous mammals such as macropods the isotopic composition of their tissues (including bone collagen, dentine, tooth enamel and hair) is primarily a function of diet and water intake (Ben-David and Flaherty, 2012; Norman Wilson, 2013). Essentially, carbon isotope ratios ($\delta^{13}C$) reflect relative intake of different vegetation types, nitrogen isotope ratios ($\delta^{15}N$) vary with annual precipitation, and oxygen isotope ratios ($\delta^{18}O$) are linked to ingested and metabolic water (Heaton et al., 1986; Clementz, 2012). These fundamental relationships have formed the basis for multiple archaeological studies (e.g. Balasse, 2002, Balasse, 2003; Balasse and Ambrose, 2002; Cerling and Harris, 1999; Fisher and Valentine, 2013; Henton, 2012; Stevens et al., 2013) but have also provided the necessary framework from which macropod isotopic research has been developed.

Given these relationships, an advanced understanding of macropod diet is critical to disentangling the complex paleo-ecological records preserved in their bones and teeth. For example, water consumption in macropods is variable and habitat-dependent. In general, macropods meet between 20% and 45% of their water requirements from dietary plant matter (but it can be as high as 100% in non-obligate drinkers) (Ayliffe and Chivas, 1990). Furthermore, while all macropods are herbivorous foregut fermenters (Hume, 1982), there are substantial differences in diets between species. Sanson (1978) defined three separate types of dietary feeding strategies based on dentition: (i) browsing; (ii) intermediate; (iii) and grazers. In this classificatory system browse refers to soft non-abrasive feed including foliage while graze refers to harder more abrasive grasses. While ecological observations and ethnographic records often attest to more complex macropod diets (e.g. Codding et al., 2014), Sanson's (1978) classification offers useful approximations to guide research. In general, the category to which a species belongs is strongly correlated with their body size; larger species tend to be predominantly grazers while small species mostly browse and intermediate sized species employ mixed strategies (Jackson, 2003). Diet is also strongly influenced by the nutritional properties of habitat as demonstrated by the fact that preferential grazers may revert to browsing in arid environments due to water stress (Forbes et al., 2010).

Cross-linking evolution, diet and diversity in macropods with regional climate and vegetative change through time highlights their palaeo-ecological significance (Forbes et al., 2010; Johnson and Prideaux, 2004; Prideaux et al., 2007; Tedford and Wells, 1990). In archaeological contexts, macropods represent an important food source for hunter-gatherers and, as such, are a focus of quantitative zooarchaeological studies (Codding, 2011; Garvey, 2011; Pike-Tay et al., 2008; Pike-Tay and Cosgrove, 2002). Given that macropod remains are a ubiquitous presence within palaeontological and archaeological contexts, it is relevant that they also become a focus for isotopic research.

Mineralized tissues (namely bone, tooth enamel and dentine) are most often preserved in archaeofaunal assemblages and thus have the greatest potential for isotopic inquiry (Hillson, 2005). This review focuses specifically on (i) macropod bone collagen as a commonly identified archaeological material (particularly in historic and Holocene