Seasonality of Weipa shell mounds: Implications for current archaeological models in northern Australia

Chantal Wight

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ABSTRACT

This thesis presents the results of an investigation into the seasonality of shell mound use at Weipa in Albatross Bay, far northern Queensland. Shell mounds are an important part of the Holocene archaeological record and have been a focus for coastal archaeologists in northern Australia for more than fifty years. Debates on their use and the socio-cultural practices that led to their formation have included discussions on seasonal occupation, but this is difficult to test using conventional archaeological approaches. This research has investigated the season of death of 12 *Marcia hiantina* shells using oxygen isotope analysis. The research question focuses on when phases of mound accumulation occurred, specifically, how this is reflected within the structure of the mound.

Oxygen isotopes provide the opportunity to test seasonality but have rarely been applied in Australian archaeology. Oxygen isotope values recorded the ratio difference between the isotopic weights of ^{16}O and ^{18}O (presented as a $\delta^{18}O$ value). The samples from SM:88 span three stratigraphic layers and a period of ~300 years. Spot sampling was conducted across the outer shell layer from the mid-point to terminal margin along the direction of growth.

The $\delta^{18}O$ analysis suggests predominantly dry season exploitation of *M. hiantina*, with a transition to wet season occupation in the uppermost excavation unit that coincided with a marked decrease in shellfishing activity. The dominance of dry season occupation contrasts with many of the current models of occupation and subsistence practices, since they favour coastal wet season exploitation. Further investigations should include a systematic investigation of a larger number of shell mounds at Weipa, as well as more broadly within other regions, to gain a clearer understanding of subsistence practice across northern Australia, or if we need to revisit existing models considering this new and emerging field of data collection.

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed

Date 5th June 2020

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CHAPTER 1 INTRODUCTION

The shell mounds of northern Australia have been a focus of archaeological research for more than fifty years (Bailey 1977; Wright 1971). During this time, many researchers have investigated their function, formation processes, and distribution patterns (Bailey et al. 1994; Beaton 1985; Faulkner 2013; Haberle and David 2004; Hiscock 1999; 2007; Faulkner 2014; Veitch 1999). More recently, a holistic approach has been adopted in addressing questions about chronology, formation and use, and towards examining links between environmental / climate variability and changes in human behavioural patterns observed in the archaeological record (see, for example, Bourke 2003; 2004; 2005 Faulkner 2013:3; Morrison 2003; O'Connor 1999).

While many researchers discuss models based on shellfish harvesting during the wet season or immediately following (Bailey 1977; Bourke 2004, 2012; Clune and Harrison 2009; Faulkner 2013; Morrison 2013a, 2014, 2018), few studies have sought to understand seasonality of shell mound use in Australia. Using sclerochronology and stable oxygen isotope analysis, this thesis analyses the seasonality of shellfish collecting practices for shell mounds surrounding Albatross Bay at Cape York Peninsula, Australia. Being able to determine seasonality will contribute broadly to our understanding of formation processes and their role in past economies and lifeways in the region, and specifically to our knowledge of the phased formation and function of shell mounds, attendant production strategies, frequency of site use and season of site use.

Shell mounds in the archaeological record

Shell mounds are heaped anthropogenic shell deposits found worldwide, including the northern latitudes of Australia. They are one of three prominent structural features (the others being the more common shell middens and shell scatters) referred to under the broader category of shell matrix sites, features or deposits (Claassen 1998; Holdaway et al. 2017). Although there is no universal classification for shell matrix site types, the definitions outlined in Claassen (1998:11) and Morrison (2010:3–4) and adopted by this author are widely accepted (Table 1).

Shell Matrix Type	Ground Surface	Height
Scatter	Visible within the deposit	0 cm
Midden	Not visible within the deposit	< 5 cm
Mound	Not visible within the deposit	> 5 cm

Table 1 Typology of Shell Matrix Deposits derived from Claassen 1988:11 and Morrison 2013a:80-81. Used when considering a shell deposit over a 1 m^2 area at the point of greatest concentration.

Shell mounds are found adjacent to marine ecosystems such as coastlines and estuaries, and in some cases, near freshwater wetlands, rivers and lakes (Bailey et al. 2019:594; Saunders 2014:42). They often contain artefacts, cooking hearths, faunal remains and human burials, and provide direct evidence of past hunter-gatherer economic, social and cultural practices. Shell mounds display a high level of variability in composition, dominant species, mound shape and formation, even at a regional and local scale (Bailey 1999:155; Codding et al. 2014:145–146; Faulkner and Clarke 2004:23; Hiscock 2008:17; Thompson and Andrus 2011:316). Mounds have frequently been the focus of comparative research on topics including shellfish as a source of food, seasonality in relation to when the shellfish were gathered, changes in ecological conditions over time inferred from species analysis, and forager or collector settlement patterns (Bailey 1993; Claassen 1998:7; Shiner et al. 2013:71).Over the past ten years there has been growing interest in determining the seasons of harvest for molluscs found within shell mound sites (Álvarez et al. 2011; Andrus 2011; Andrus and Thompson 2012; Brockwell et al. 2013; Burchell et al. 2013; Finstad et al. 2013; Hallmann et al. 2013; Harke 2015; Jew and Fitzpatrick 2015; Leng and Lewis 2016; Schöne and Gillikin 2013; Twaddle et al. 2015; 2017). The continuing refinement of estimates gauged from geochemical analysis, particularly through stable oxygen isotope ratios and pairing with sclerochronology, allows researchers to identify the season of harvest as well as the environmental conditions for the life span of the individual mollusc. (Burchell et al 2013; Cannon and Burchell 2009; Hallman et al. 2009). Together these data have the capacity to enhance our understanding of the seasonality of particular phases of mound formation, and how that might have varied throughout the building phase of individual shell mounds and within clusters of contemporaneous sites.

The question of seasonality has been a recurrent theme in understanding hunting and gathering societies, and is an important if not fundamental element to site interpretation (e.g. Attenbrow 2003; Bailey 1975; Barker 1999; Bourke 2004; Claassen 1982; Faulkner 2013). As shellfish are typically available to some extent throughout an annual cycle (Meehan 1982), the presence or absence of a species is not a reliable indicator of seasonality. Given the sheer volume of shellfish contained within a shell site, it is often speculated that these were a resource targeted when in abundant supply (e.g. Bourke 2003; Clune and Harrison 2009; Faulkner 2013). Models of seasonality across the northern latitudes of Australia vary, some advocate for the wet season or verge on the transition into the dry season (e.g. Bourke 2012; Clune and Harrison 2009; Faulkner 2013) whereas others advocate for the dry season (Twaddle et al. 2017).

Research design

This study will enhance our understanding of the social and cultural dynamics surrounding the use of shell mound sites near Weipa, found around the shores of Albatross Bay, and dating from the mid–late Holocene. In order to do this, the research has been framed around the following question:

> Can seasonality be determined for phases of shell mound use at Weipa using oxygen isotope analysis, and what does this reveal about the human behaviours linked to the subsistence practices of harvesting shell?

Fundamental to answering this question is determining the seasonal use of such sites (Burchell et al. 2013; Eerkens et al. 2013). Assigning the season in which the mounded shellfish died can inform us on when people used the site. Aligning this with individual mound layers can indicate the intensity of harvesting at these periods (e.g. presence of large groups or smaller groups). Through this information, patterns of resource use can be identified, as well as inferences about how people adapted their lifeways across seasonal changes. To do this, seasonality will be determined by applying stable oxygen and carbon isotopes and sclerochronological analysis on the species *Marcia hiantina* (Lamarck, 1818). This species is one of the two dominant species retrieved from shell mounds in this region, the other being *Tegillarca granosa* which is the shellfish most commonly recorded within the literature for northern Australian shell mounds as the dominant species.

The core aims of this research are to:

- Examine current research regarding mounds and seasonality;
- Determine what season shells were harvested from in an individual shell mound at

Prunung, Weipa;

- Assess the implications of the findings against the mound function and formation models for northern Australia; and
- Enhance our understanding of the relationship between the exploitation of particular resources and occupation in comparison with other shell mound sites in northern Australia.

This study focuses on a shell mound complex at Prunung, near Weipa, in Cape York Peninsula, and which is comprised of several shell mounds (Morrison 2013b, 2015). One of the smallest of these is SM:88, a low shell mound positioned away from the main cluster 450 m from the contemporary shoreline and beyond the impact of recent storm surge events. This research will analyse the isotopic oxygen ratios captured in the shell from each of the seven excavated spits to understand what season they were collected.

Significance

This study is significant because it is the first to use oxygen isotope analysis to link the seasonality of shellfishing practices to shell mound formation in Cape York Peninsula. As such, this research contributes and refines our knowledge of hunting and gathering societies in coastal northern Australia, and provides new understandings that can help guide future research

Limitations

The key limitations to this research were two-fold. Firstly, modern specimens of *Tegillarca granosa* (Linnaeus, 1758) were unavailable. Through personal conversations with Professor Geoff Bailey who recalled their prolific availability during his research as a PhD student in the 1970s, and Morrison (2003) who documented contemporary oral accounts of people gathering *T. granosa* by the rake full, this contemporary unavailability faced by this researcher and others (Twaddle 2016) is relatively recent and most likely eventuated from the dredging of the Prunung (Andoom) channel by Rio Tinto for mining purposes, removing the previously existing habitat suitable for this shellfish. Consequently, the focus altered from the analysis *T. granosa* to that of *Marcia hiantina* (Lamarck, 1818), the second most recorded species near Weipa (Cochrane 2014; Morrison et al. 2018).

Secondly, the availability of suitable shell for sampling from the lowest excavated unit (XU), XU07, was problematic, due to the lack of intact shell, resulting in one viable shell for sampling. As documented by Morrison (2010:274) some recrystallisation was evident in a few of the shell submitted for C14 dating from the upper layers, and of the two complete shell valves retrieved from XU07, partial sections of the periostracum layer of one valve was not intact nor in a state of otherwise good preservation. While there was an abundance of shell, most were broken and missing a direct intact path from umbo to terminal margin. This fragility of shell is a quality of *M. hiantina*, compared with the denser, robust shell of *T. granosa*.

Chapter outline

A review of previous archaeological research on shell mounds in Australia and globally is presented in Chapter Two, providing a summation on the central archaeological models for mound function and formation and debates regarding seasonality. Chapter Three reviews previous research on shell mounds at Weipa, and Prunung in particular, and outlines the current knowledge regarding palaeo-environmental and climatic conditions for the region.

The methods and materials used in this research are detailed in Chapter Four. This includes details of the excavation methods used by Morrison (2010) to obtain the samples analysed here, initial laboratory sampling criteria, testing specimens for recrystallisation, and stable oxygen isotope analysis. Chapter Five presents the results from the laboratory analysis of the shellfish with details included in the appendices.

Chapter Six discusses and interprets the results in relation to the known history of the site and wider body of shell mound literature presented in Chapters Two and Three. Chapter Seven concludes the research by analysing these findings against the research aims outlined in Chapter One.

CHAPTER 2 SHELL MOUNDS IN ARCHAEOLOGY

This chapter provides an overview of the key global debates relating to shell mounds in the archaeological record, including how past societies have viewed shellfish and shellfish collection. It contextualises this study in relation to Australian shell mound research, specifically in the northern latitudes. It outlines the gaps in current models for shell mound function and formation, and considers how this study can add clarity to some of the broad questions that remain unanswered.

Changing interpretations of shell mounds

Shell mounds are highly visible and theoretically, with the exception of high alkalinity (see Linse 1992), provide an ideal environment for the preservation of bone and other organic material due to their high calcium carbonate content and its neutralising effect on soil pH (Andrus 2011:2892; Bailey 1999:108; Barker 1999:123; Beaton 1995:804; Claassen 1998:87; Koppel 2017:23; Morrison 2003:4, 2013a:85; Shiner et al. 2013:71; Rick and Waselkov 2015:344; Waselkov 1982:72). These factors have made shell mounds a significant focus of archaeological investigation.

Occurring near tidal estuaries and palaeo-coastlines, often along low sand ridges (Faulkner 2013; Holdaway et al. 2017:1), shell mounds are regularly noted edging different ecological zones such as on alluvial flats between shorelines and hinterland (Bailey 1977:132, 133, 135), around seasonal swamps and plateaus (Morrison 2010:272, 2013b:182). Over the years, many theories have been debated as to their function, location and formation, including as rubbish mounds, shelter structures, food preparation platforms, an escape from biting insects, raised dry ground during wet season, suitable habitats for fruit bearing trees (or domiculture), and camp sites (Bailey 1977:140; Cribb 1986; Hiscock 2008:175–178; Morrison 2003:2; Stone 1995).

The interpretation of shell mounds and middens as anthropogenic dates from the 19th century (Darwin 1839:234; Gunn 1846; Statham 1892). Researchers at that time concentrated their analysis on artefacts and other features within the mounds, and site formation processes and shell types were generally ignored (Howarth 2009:10–12). It was not until the mid- 20th century that North American researchers turned their attention to the actual shellfish and questioned what could be learned from their analysis (Koppel 2017:2). Around a similar period in Australia, Wright undertook the first rigorous archaeological excavation of two shell matrix sites, targeting the large Weipa mounds

(Wright 1963; 1971). Wright's work was undertaken in response to suggestions that the shell mounds near Weipa were of natural origin, formed by coastal and chenier building processes (Stanner 1961; Valentin 1959). As such, Wright's primary purpose was to determine whether the sites were naturally occurring or anthropogenic (Wright 1963, 1971).

Bailey (1975; 1977) later expanded on Wright's work to formally analyse the shell mounds near Weipa, asserting that they were in fact anthropogenic (Bailey 1975, 1977; Bailey et al. 1994; Morrison 2010:98–100; Shiner et al. 2013:67). More than ten years later, Stone (1989,1991,1995) reignited the debate and argued that, given the enormous size of some of the shell mounds, they could not be cultural but instead the result of natural shell deposits being scraped up into scrub-fowl nests. Such nests have been known to reach similar heights, though their walls are often steeper. Following the general discrediting of Stone's initial papers (Cribb 1991; Bailey et al.1994), much consideration has been given to determining the difference between natural and cultural mounds.

Essentially a cultural mound will exhibit (modified from Bailey 1977:133; Bailey et al. 1994:71):

- a sequentially aged stratigraphy;
- species selection of a size targeted for consumption;
- artefacts;
- non-marine faunal remains; and
- evidence of subsistence and resource exploitation.

Natural mounds will exhibit:

- disturbed stratigraphy;
- more marine sand;
- random assemblage of local aquatic environment; and
- lack of size selection in the assemblage.

Cheniers and chenier plains are natural beach ridges, often incorporating shell, with intervening mudflats (Augustinus 1989:219; Horne et al. 2015; Lees and Clement 1987:331) devoid of artefacts. Note that whilst bird mounds are known to include artefacts and culturally modified shell, their stratigraphy is disturbed.

In the 1970s, researchers became interested in the role of shellfish as a food source, leading to the development of methods for equating the volume of food remains with nutritional value. The aim of this work was to determine the amount of flesh collected and the calorie intake attainable as a means of making an estimate of population size (Bailey 1975:54–56, 1977:138–139, 1993:2; Erlandson 1988; Meehan 1982). Many early researchers in this field viewed shell mounds as a representation of overall dietary intake, and therefore attributed up to a 90% reliance on protein (shellfish) for a community's subsistence (Noli and Avery 1988:395, 397). However, it quickly became apparent that these structures provided a snapshot of resource exploitation particular to that location, over a prolonged period of time, for what may have been a small number of days per year and calculations were adjusted to incorporate these variables to provide more measured caloric models (Erlandson 1988; Noli and Avery 1988:398–399). More recently the work of Kyriacou (2017) has revisited shellfish and their role as a significant source of protein, most likely targeted by small groups of highly mobile hunter gatherers.

Shell mounds are often viewed in economic terms relating to intensification or a broad-spectrum revolution via the targeted exploitation of a resource on a large scale (Barker 1999:199; Clune and Harrison 2009; Haberle and David 2004; Harrison 2009; Luby and Gruber 1999; Meehan 1982; Morrison 2003, 2013a, 2013b; Rosendahl et al. 2014; Veitch 1999). From the late 1990s, some archaeologists argued that environmental variability during the mid–late Holocene caused considerable change in human subsistence practices and occupation patterns (e.g. see O'Connor 1999; Faulkner 2008, 2009, 2013). They argued that due to a combination of rapidly rising sea levels, increased aridity and intra/inter seasonal variation, people lost access to traditional hunting and foraging zones (Bourke et al. 2007; Faulkner 2009; Hiscock 1999, O'Connor 1999). Furthermore, through these climatic shifts, the environments that sustained key ecosystems significantly declined or disappeared forcing the adoption of new strategies to exploit new resources in previously uninhabited areas (Bailey 1999; Bailey et al. 1994:79; Beaton 1985; Bourke 2003, 2005; Bourke et al. 2007; Brockwell et al. 2013; Codding et al. 2014:146; Faulkner 2008, 2009, 2013; Faulkner and Clarke 2004; O'Connor 1999; Rowland 1999; Shiner et. al 2013). A contrasting response to this environmental and economic-driven model has been the study of site formation processes, with changes in resource harvesting viewed as a reflection of social and cultural dynamics rather than forced by environmental factors (Clune and Harrison 2009; Morrison 2003, 2013a; Rosendahl et al. 2014).

How people 'see' shellfish

The primary means of subsistence for most hunter-gatherer societies is attributed to gathering activities, a classification which encompasses shellfish harvesting, with gathering activities forming a greater proportion of subsistence practices with increased proximity to the equatorial zone (Bowdler 1976:249; Claassen 1982:4; Lee and De Vore 1968:41–42; Meehan 1982:7; Moss 1993). For over a century shell mounds have been recorded by archaeologists, ethnographers and anthropologists studying communities that have an historic association with, or that continue to practice, shellfish gathering activities (Bourke 2005:44; Faulkner 2013:6; Meehan 1982:5; Moss 1993:632). Given the high visibility and good preservation of these structures, it is surprising that early accounts generally overlooked the role of shellfish. Meehan (1982:7) and Moss (1993:632, 637, 639) have linked this previous exclusion of shellfish in part to the majority of those researchers being male; the fact that shellfish collecting is frequently the domain of women and children would have limited researchers' opportunities to accompany women during these events. Further, Meehan (1982:7) and Moss (1993:631) both note that hunting activities—dramatic and fast-paced—were more engaging to a researcher's interests, reducing shellfish harvesting to an insignificant side activity.

Moreover, shellfish have been viewed in a secondary light, if not a negative light. In Meehan's (1982:7) review of attitudes towards shellfish collection, it was deemed a marker of a 'primitive' society, as it appeared to require no sophistication, ingenuity or development of technology for a successful harvest. It was therefore seen as a food source for those who had not yet developed the technical prowess for procuring 'higher' resources, as a fall-back food for bad seasons and famine where other resources had failed, or as an easily accessible resource at times of expansion into new areas (Clune and Harrison 2009:77; Erlandson 1988:102; Meehan 1982:110; Stiner 2001:6994; Waselkov 1982:40; Zeder 2012:245). Moss (1993:641–643) notes that this negative association with shellfish is not limited to researchers but can also extend to communities who regularly engaged in shellfish harvesting. The Tlingit of Alaska were one such community, who viewed shellfish as a dubious food and its collection as appropriate primarily for people of low status, or who were poor (Moss 1993:641). Hastorf (2017:187–189) examines whether the Tlingit community's attitudes towards shellfish being impure extended from gender bias or the ease of harvesting/collection; since shellfish were easily accessible to all members of the community their gathering thereby became socially less elite.

In the 1970s and 1980s, studies began to include the role of shellfish in terms of diet and economy. And since the 1990s, a growing number of papers have focused on the role of shellfish in relation to gender, status, social, symbolic and cosmological meaning (Luby and Gruber 1999; Moss 1993). Among the Tlingit of northwest America, as is the case with the majority of recorded hunter-gatherer societies, shellfish collecting was the work of women, children and ‘lazy men’ (Beaton 1985:4; Clune and Harrison 2009:78; Meehan 1982:119, 131; Moss 1993; O’Connor 1999:48). The knowledge of where and when shellfish could be harvested was not exclusive to the Tlingit women, but equally shared with the men (Moss 1993:635). The men only utilised this knowledge, however, when there was not enough time to hunt, such as when moving into new areas or during ceremonial events. Moreover, dietary restrictions were associated with the consumption of shellfish, more so for those of notable social status. A symbolic fear was attached to shellfish consumption and harvesting. Tlingit believed harvesting or eating shellfish or dreaming of clams brought poverty on their families (Moss 1993:641). Social restrictions were also placed on when people could eat shellfish. Ceremonially, people were considered unclean and abstaining from eating shellfish was required to attain purity. Women at the onset of menstruation, after childbearing and when widowed were also prohibited from eating shellfish, sometimes for several years (Moss 1993:642).

Interestingly, in some cases the Tlingit shell beds were known to be owned by particular groups or families, as a corporate group, denoting economic value (Moss 1993:635). Similar associations of ownership have been documented for Weipa (Morrison 2003:6). Luby and Gruber (1999:99–100) have considered the San Francisco Bay shell mounds in terms of corporate ownership, specifically in terms of ‘aggrandizers’ and the accumulation of social standing and cultural wealth. They accept that not all hunter-gatherer societies are egalitarian (Luby and Gruber 1999:98) and that symbolic meaning in such societies is often given to what would now be considered commonplace, food and home being of particular significance. Shell mounds represent both food and a level of occupation (Luby and Gruber 1999:102). Moreover, these mounds are ceremonially associated with thousands of burials, giving them additional cultural meaning. Luby and Gruber (1999:97–100) link cultural meaning and ceremony to subsistence. In this instance, feasting ceremonies on mounds indicate the previous success of harvests by their ancestors. The subsequent returning of remains to the mound from their own harvest symbolises an ongoing connection, by feeding the dead and ritually asking for the provision to continue. The aggrandizer would have a ‘corporate group control’ (Luby and Gruber 1999:99) over the shell beds and acquire social and cultural wealth through hosting these feasting events with neighbouring groups. McNiven (2013) brings these discussions into an Australian framework, dismantling the already somewhat questioned assumption of shell mounds as ‘rubbish’, that is, the standalone by-products of hunter- gatherer subsistence.

Rather than being a structure of discard and fleeting meaning, McNiven (2013:580) argues that shell mounds can signify/symbolise a connection and ownership over an area through continued occupation, beyond active use and accumulation.

Shell mounds in northern Australia

The emergence of shell mounds and other shell matrix sites has been widely linked to the stabilisation of sea levels around 6000 BP (Beaton 1985). With exceptions, shell mounds register in archaeological sequences worldwide during the mid–late Holocene, c. 5000-4000 BP (Barker 1999:119). This trend is replicated in the dating of shell mounds across the northern latitudes of Australia and few pre-date 4200 BP (Figure 1) (Beaton 1985; Bourke 2003:42; Clune and Harrison 2009:70; Harrison 2009:81; Meehan 1982:3; Morrison 2010:362, 2013a:79; O'Connor 1999:37; Veitch 1999:56).

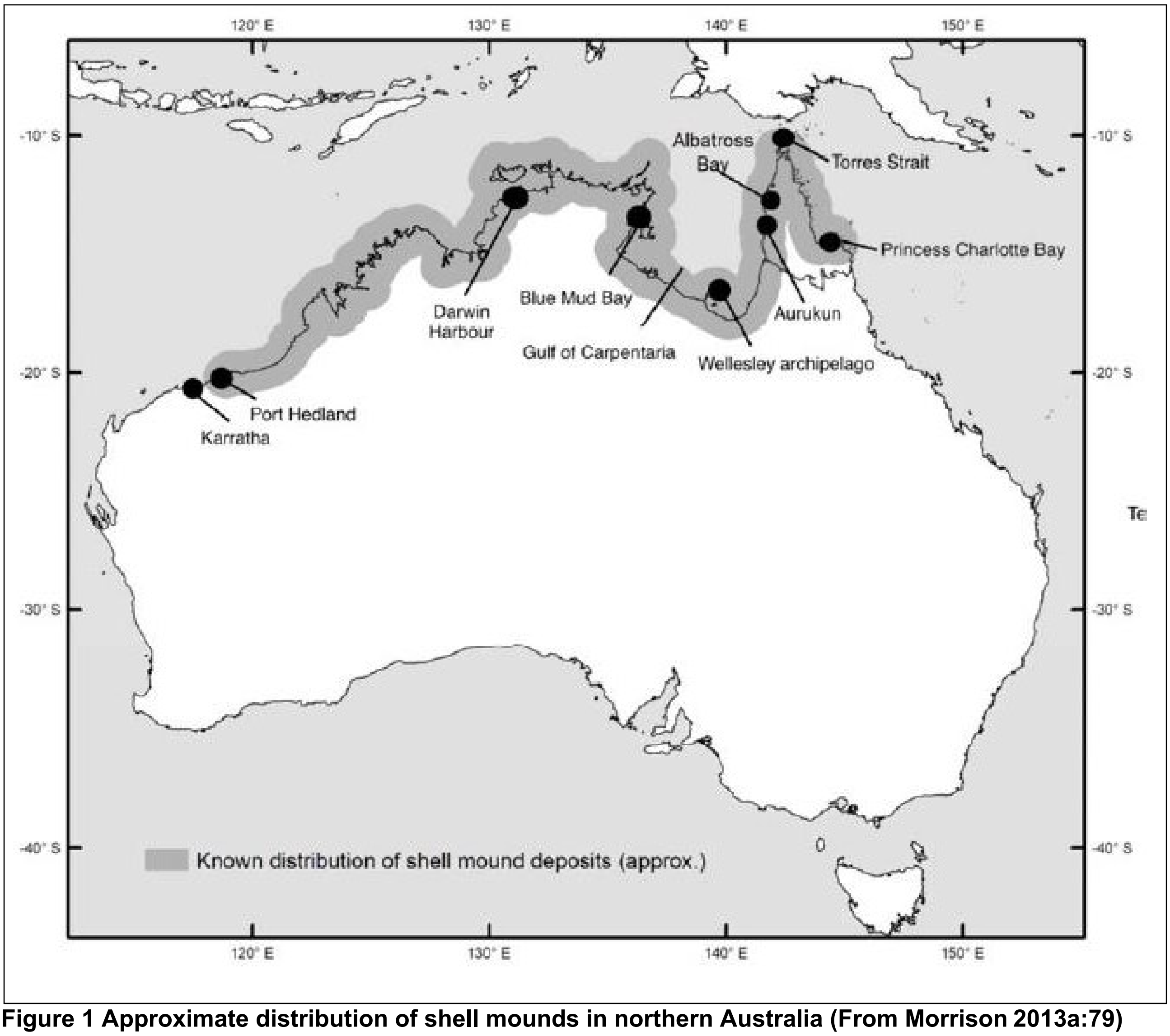

Figure 1 Approximate distribution of shell mounds in northern Australia (From Morrison 2013a:79)

The earliest mainland recorded sites are along the north-west coastline of Australia with age determinations for Western Australia ranging from Abydos Coastal Plains at c. 5300

BP to c. 3500 BP for the Kimberley (Clune and Harrison 1999; Harrison 1999; O'Connor 1999; Veitch 1999). The Northern Territory shell mounds age from c. 3000–2000 BP (Bourke 2003, 2004; Brockwell et al. 2013; Faulkner 2008, 2009; Meehan 1982). Queensland presents age determinations for the Wellesley Island shell mounds at c. 3300 BP (Rosendahl et al. 2014); further east, Cape York Peninsula ages have recently been pushed back from c. 2700 BP (Morrison 2013a; Shiner et al. 2013) to c. 4000 BP (Holdaway et al. 2017).

Age determinations on mounds on offshore islands along the northern Western Australia coast have provided upper age determinations of ~315 cal BP (Holdaway et al. 2017; Rosendahl et al. 2014). This contrasts with earlier models that depicted mound termination as following the northern latitudes in an easterly direction, culminating in the youngest mounds being in Weipa, Cape York Peninsula (O'Connor 1999; Stone 1995:77). Similarly, it was also believed that the cessation of mound development loosely followed the same pattern (Bailey 1999:110; Beaton 1985:9; Rosendahl et al. 2014:263).

Overall, there is no consensus about the cessation of mound building. O'Connor (1999) claimed mound building in Western Australia (WA) ceased around 1000 BP. This age has been rejected (Clune and Harrison 2009; Harrison 2009), with other ages indicating the mound building phases continued into the twentieth century. Based on *Tegillarca granosa*, claims for the Northern Territory (NT) assert an end age of 500 BP (Bourke 2003, 2004; Bourke et al. 2007; Brockwell et al. 2013; Faulkner 2008, 2013). These authors have extrapolated these termination ages for the entire mound building activities across tropical northern Australia. The main obstacle in accepting this generalised view are the ages from the western Gulf of Carpentaria including the Weipa mounds. These mounds, while the youngest, are the 'largest and most numerous' (Stone 1995:77) in Australia. Ethnographic accounts of shell mounds being in use post-contact have been confirmed by radiocarbon ages and the presence of post-contact materials within the mounds (Morrison 2013a:80, 2014:10–11). Further evidence is provided by Rosendahl et al. (2014) for the Gulf of Carpentaria, where results have indicated shell mounds to be in use at 280 BP with the possibility of continuing post-contact, albeit with a very different taxonomic composition.

The majority of mounds in northern Australia are dominated by *Tegillarca granosa* (syn. *Anadara granosa* (Linnaeus 1758)), which forms up to 90% of their composition by weight (Bailey et al. 1994:69; Bourke 2005:30; Clune 2009:77–78; Fanning et al.

2018:44; Faulkner 2013: Morrison 2003:2, 2013a:78; O'Connor 1999:47; Veitch 1999:51). Despite this, there is increasing evidence of species variability within shell matrix sites. This variability includes: Norman Creek, south west of Weipa, where the primary species was ≥95% *Marcia hiantina* (Lamarck, 1818); Archer River, South of Weipa, where *T. granosa* was wholly absent and the primary species were *Telescopium telescopium* and *Geloina erosa*; Wellesley Islands, in the southern Gulf of Carpentaria, where shell mounds are defined either by the gastropods *Terebralia spp*. and *Telescopium telescopium* or the bivalves *Anadara antiquata* and *Saccostrea* sp. (Cochrane 2014:47–48; Rosendahl 2014:264); and, Skew Valley in Western Australia, where there was a shift in species dominance from mangrove gastropods to *T. granosa* approximately 4000 BP (Clune and Harrison 2009:71).

The previously recorded dominance of *T. granosa* could represent a bias of off-site preparation of other shellfish and faunal species or site exclusivity for mollusc exploitation. Furthermore, *T. granosa is* likely to have a lower susceptibility to taphonomic processes given their robust structure compared to finer molluscan species such *Marcia hiantina* (Morrison 2013a:88).The lack of bone in shell mounds has been widely documented due to the high soil acidity in Cape York and other coastal zones. This leads to the rapid decomposition of materials off-mound and has been a well-documented issue for preservation (Linse 1992; Morrison 2013a:82; Rowland 1999:144). However, this does not explain the lack of non-molluscan faunal material within shell matrix sites. The internal composition of a shell mound is highly alkaline resulting from the calcium carbonate component leaching the individual shells en masse, an environment which should ensure high preservation rates within the shell structure (Andrus 2011:2892; Morrison 2003:4, 2013a:82). Claassen (1998:54) notes that leaching and immersion create preservation issues within mounds particularly through the lower sections, but that these effects reduce towards the top layers. Therefore, the lack, or limited presence, of non-molluscan fauna cannot solely be a preservation issue since it is recovered in small quantities. A recent thesis (Evans 2020) provides a detailed account of the complex taphonomic processes at play, particularly the impact of heat, physical fragmentation and subsequent chemical decay and deterioration on non-molluscan fauna contained within SM:93, also at Prunung, Weipa.

Australian models for shell mound formation and use

The following section discusses some of the more prominent models posited for shell matrix site development in Australia and the more incremental models for how people used and contributed to creating these sites on a more regular basis, i.e. daily, seasonally, annually. These models are vital to this research as they provide a framework for testing the seasonality results from the archaeological shell retrieved from SM:88 at Prunung.

Time lag model

Beaton (1985) investigates when and under what conditions the settlement/occupation of coastal zones (intertidal and estuarine) occurred in Australia. He states that until the mid-Holocene there was no stable coastal occupation in Australia and that there was a one- to two millennia 'lag' from when sea-levels stabilised after the last marine transgression (LMT) to initial coastal occupation. In relation to Princess Charlotte Bay in far north Queensland, Beaton claims the lag was a response to the time required for the intertidal zones to recover from the impact of the LMT and establish mudflats suitable for *T. granosa* beds capable of supporting an increasing human population with a more sedentary lifestyle. Equally, he claims continuing environmental shifts that saw the depletion of the shell beds, thereby causing the abandonment of these sites (Clune and Harrison 2009:76). The time-lag model is supported by Faulkner (2013) in his investigations of the Blue Mud Bay area and their appearance along the coastline from 3000 cal BP, post sea-levels stabilising around 6000 cal BP.

Environmental model

The environmental driven model reasons that mounds were formed in response to a new and abundant resource, particularly *T. granosa.* The exploitation of this resource represents a survival strategy in the face of climatic and environmental stress (Barker 1999:119; Bourke et al. 2007:91; Brockwell et al. 2013:21; Codding et al. 2014:146; Rosendahl et al. 2014:256; Rowland 1999:141; Turney and Hobbs 2006:1745, 1747). Bourke's (2005) analysis of two mound sites at Hope Inlet indicates different patterns of use and development. At Middle Arm, mounds are smaller and formed over long periods suggesting low intensity mobility and harvesting practices. Hope Inlet features large mounds which Bourke equates to 'large bulk processing site[s]' with potential connection to large ceremonial gatherings. The size, formation and duration of these sites are solely attributed to the rate of availability to resources per environmental factors. Faulkner (2008) calculates that periods with an absence of radiocarbon ages indicate a hiatus in site use as a result of environmental variability that temporarily depleted local food resources.

Social and cultural factors

Rosendahl et al. (2014) more recently have opposed environment causality with evidence from the Gulf of Carpentaria, particularly the Wellesley Islands, showing a substantial shift in occupation patterns and a rise in new site types, principally shell matrix sites, which cannot be linked to environmental changes. An increased population, understanding of the natural resources, exploitation of already known resources and contact with Macassans for trade and exchange are far more likely to account for this shift, according to Haberle and David (2004).

Clune and Harrison (2009) propose that the emergence of large shell mounds was governed by social factors. Based on ethnographic records, they find the Abydos Coastal Plain mounds were occupied annually following the wet season, for ceremonial purposes when intertidal resources were abundant (see also Harrison 1999). Similar models have been proposed by Luby and Gruber (1999) as discussed above though not as sites of increased sedentism. Morrison (2003, 2013a) states the Weipa mounds are not an environmental response but the site of repeated short-term gatherings for ceremonial purposes, social reasons or kin-based events such as marriages. The location of these sites is selected based on the availability of abundant resources that are easily exploited. Again, in this model increased sedentism is not favoured.

Clinal model

The clinal model favours environmental causality and supporters claim that site occupation and density were unequivocally linked with environmental factors (O'Connor 1999). When optimal conditions provided abundant *T. granosa* shell beds, larger gatherings would occupy the sites for longer periods. Conversely, when environmental conditions produced a low yield, smaller groups would exploit these resources with a higher mobility. The exploitation of these resources during lean years was almost exclusive (Morrison 2013a). A key feature of this model is the assertion that the emergence of shell mounds followed the northward regression of the monsoon. As such, shell mounds to the south should pre-date the younger mounds further north (O'Connor 1999). Veitch (1999) rejects this model in favour of mounds signifying a period of growing focus on the highly reproductive r-selected species (Veitch 1999:57-59), with the appearance of microliths and points, and no dependence on a single resource however temporary. Veitch indicates exceptions throughout the Burrup Peninsula and other areas of Western Australia that do not concur with the timing of shell mounds northwards.

Ethnographic models

The work of Meehan (1982) remains pivotal for shell mound research. Her findings, which have been widely accepted, provide insight into formation of shell mounds and the people who build them, as well as offering frameworks for comparative studies. Through a yearlong study in the early 1970s of the Anbarra people in the Northern Territory and their shellfishing practices, Meehan developed a model for shellfish and shell matrix sites. Her findings determined that shellfish provided an easy and reliable source of food that, while important to the Anbarra diet, was never a major contributor. It took little energy or time to produce a high food return. Meehan noted that when shell beds were negatively affected or destroyed by seasonal fluctuation, they were quick to return, often by the following season. Shellfish was a fail-safe food used to supplement periods of lean resources. However, the lack of shellfish availability was not a cause of stress as there were always other resources to be procured (Barker 1999; Meehan 1982). The level of year-round exploitation was dependent on a number of factors, including lunar phases. Low tides were particularly strong during full and waning moons, as reported by Luby and Gruber (1999) for the San Francisco Bay, Klein and Bird (2016) for southern and north-western Africa, and Jeradino and Marean (2010) for the east coast of South Africa, which provided optimal times for extensive harvesting. Important ceremonies were another occasion for mass collection.

The Anbarra had three types of shell site. Processing sites were the most ephemeral, being located close to a shell bed and used for cooking the flesh before returning to the home base. These typically represented a single event targeting of an individual species (Meehan 1982:117). Dinnertime camps sometimes represented a single event, and at other times were used repeatedly, but they were not sites of occupation. Instead they were typically used by women and girls for processing the foods they had collected earlier in a day (Meehan 1982:112–114). Home bases were the most sedentary of the three, often being used over months or occasionally years. They were similar to dinnertime camps but did not feature the informal exclusion of men and boys. Food collected during and not consumed through the day would be brought to these sites for wider group consumption (Meehan 1982:114-116).

Seasonality models

Outlined here are several critical arguments about how seasonality is deemed to sit within these Australian models of mound function and formation. Determining and understanding seasonality is an important, factor for understanding who used shell mounds and when. This includes how these features were developed over time, beyond the broad-brush strokes of beginning, ending and the gross changes in between. Seasonality is one of the major elements that can provide an in-depth understanding of the role these sites played.

Bailey (1977:139) argued that the Weipa shell mounds operated as refuge campsites during the wet season when shellfish and other marine animals were in abundance, proposing that shell sites provided a raised surface to avoid waterlogged ground. Favouring Peterson's (1973) model, he posited (Bailey 1977:139) that given the focus on low lying areas during the wet season—high tides leading to flooding of marshes and salt pans and consequent easy fishing—shell mounds provided a dry, insulated surface for camping close to resources. As the wet season peaked, the increase in flooding, storms and storm surges would temporarily drive people further from the shoreline, behind the beach ridges to the border of the woodland zone until conditions eased and they could return to the mounds again. People would move on to other seasonal locations for the dry season once freshwater sources diminished (Bailey 1977:140). Bailey hypothesised that the larger the shell mound, the greater the comfort provided and that larger shell mounds were evidence of more frequent occupation or revisiting. These conclusions were largely drawn from Bailey's own observances of contemporary use of mounds as cooking sites, as well as ethnographic and historical accounts (Peterson 1973; Roth 1901) from near Weipa and Arnhem Land (Bailey 1977:138–40). Noting that the accumulation layers varied significantly, Bailey interpreted this to indicate that the mound accumulations were not sites of yearly use on a regulated, predictable scale (Bailey 1977:135). With regard to the 10 Kwamter sites, he proposed that a minimal number would be in active use at one time, selected on merit based on which would yield the most that season. Here too is the argument that shellfish were not a food of reliance, but part of a larger, adaptive subsistence strategy (Bailey 1977:139).

Meehan's (1982) book, *Shell bed to shell midden*, remains a seminal resource for coastal archaeologists interpreting hunting and gathering societies. As indicated above, her ethnographic account of the Anbarra noted distinct seasonal occupation patterns including that groups were more sedentary due to flooding during wet seasons when they positioned themselves near coastal zones where food resources were more plentiful. Shellfish were a reliable food of the wet season, though targeted to a lesser extent throughout the year, contributing to a much wider diet, rather than being a focus or reliance (Meehan’s 1982:58–80). This feature became evident when shell beds were decimated following a particularly intense wet season (Meehan’s 1982:162–165). Rather than being problematic, the four community groups exploited other local food resources already practiced within their subsistence strategies e.g. fish, yam and other vegetables (Meehan’s 1982:163).

Bourke (2012:173–174) argues that shell mounds near Darwin Harbour were formed through the seasonal activities of large gatherings of people, primarily for ceremonial events. They also served wider socio-cultural purposes that extended beyond one family or community group since these gatherings were timed to coincide with when shellfish were at their peak abundance, specifically the late wet season (Bourke 2012:139 see also Bourke 2005). In contrast, Faulkner (2008, 2009, 2013) proposed that shell mounds in the Blue Mud Bay area resulted from punctuated periods of increased exploitation of shellfish when other food resources were scarce due to increasing environmental variability between 3000–500 years BP. Faulkner argues that these repeated intensive phases of shellfish harvesting and the targeting of *T. granosa* during peak abundance amounted to intensive harvesting, effectively decimating this shellfish population from what were prolific numbers, to marginal evidenced in a reduction of shell size found in the upper, younger layers of the shell mounds (Faulkner 2009: 831–832). Faulkner also argues against models that use ethnographic data as a basis to interpret gathering and mound building practices (Faulkner 2013:3). Instead he argues (Faulkner 2013:60, 138) that rather than socio-cultural factors driving these practices, it was primarily environmental and climatic conditions that influenced these behaviours through species selection and availability. Unlike Bourke (2005), Clune and Harrison (2009) and Morrison (2003, 2013a), Faulkner (2013:165–166) advocates there is no evidence for ‘low level harvesting, such as seasonal exploitation by small foraging groups, nor occasional high intensity harvesting by larger groups for ceremonial purposes’. He instead argues (Faulkner 2013:170) that the targeting of shellfish, location and species were socially ad hoc, and governed by whichever resource was abundantly available. He too advocates for wet season harvesting, based on when shellfish are most prolific rather than ethnographic data.

In north western Australia, Clune and Harrison (2009:79) review the shell sites of the Abydos Coastal Plain and the changes in species selection overtime within the shell mounds. They argue that the *T. granosa* dominant shell layers, often built on top an older layer that contained none of this species, are indicative of intensification in population, and social reorganisation. They propose a season of collection that sits on the transitional cusp of late-wet to dry season, though the two do not always correlate (Clune and Harrison 2009:77). Given the lack of other non-molluscan remains or artefacts, Clune and Harrison suggest these sites were akin to Meehan's processing or dinnertime camps, rather than sites of occupation (2009:78). However, in contrast to Meehan (1982) and Morrison (2013a), Clune and Harrison argue that these changes were implemented to meet the challenges resulting from resource stress brought on by increasing aridity, not an adaptation of an existing strategy targeting many varied food sources.

Morrison (2013a) proposes that Albatross Bay shell mounds are evidence of a concentrated, or 'niche', exploitation of a specific food resource, in this case mollusc beds, such as during peak periods of abundance. Rather than arguing for environmental factors driving this behaviour, Morrison (2013:79) acknowledges that this exploitation occurs more broadly than being solely governed by optimal environmental conditions for shellfish harvest, or when other food resources fail. In a similar way to the targeting of other food resources within Cape York Peninsula, the intensity of this harvesting practice would have been scaled significantly. Large groups working together would exploit shellfish on a larger scale, potentially over a far shorter timeframe than smaller groups. These harvesting activities were not bound to specific locales. Rather, the people moved with the proliferation of available shell beds, whether they be *T. granosa, M. hiantina*, or a lesser targeted sub species (Morrison 2013a:88). Consistent with Meehan (1982:162–165), Morrison acknowledges the wide subsistence strategies already in practice, and that should one food source be unavailable, the people were prepared and practiced in exploiting another (Morrison 2013a:88). Rather than advocating for regular, semi-sedentary, seasonal occupation of these mound sites, Morrison supports a model of far more dynamic and flexible short-term site visitation. Use would increase and decrease in line with availability of surrounding resources. Social scheduling would move within and between known locations to maximise production around large biomass events (Morrison 2013a:89).

Rosendahl et al. (2014) see shell sites on the Wellesley Islands, northern Australia, as a shift in existing subsistence practices from one resource towards that of shellfish. Unlike other sites with recorded periods of discontinued use (e.g. Blue Mud Bay see Faulkner 2009; 2013), Rosendahl et al. argue, with little supporting evidence, for continual use and an intensification of site use and population, with cessation not being caused by increasing aridity and consequent elimination of the suitable habitats for these mollusc, but through increased contact and trade with Macassans. The results from this investigation support the models of Morrison (2013a) and Meehan (1982) whereby the targeting of shellfish was one practice within an existing and flexible suite of subsistence strategies and where the people were not dependent on limited resources as their staple.

Brockwell et al. (2013) analysed oxygen isotope data from geographically separate areas in central northern Australia to advocate that climate change was the main instigator for cultural changes in northern Australia (Brockwell et al. 2013:30). Unlike other global settings, few isotopic studies of shellfish seasonality have been conducted in Australia where the focus has been to link shell fishing activities to the formation of shell mounds. While the seasonality aspect of this study indicated that the shellfish were collected in the late wet season, some variability was detected and this was largely attributed to heightened seasonality within the wet season, rather than a potential indicator of an alternative season of harvest (dry/winter). Brockwell et al. (2013:30) coupled the seasonality data with proxy environmental data which they used to create a framework that linked increased aridity to a decline in optimal shellfish habitats, thereby leading to the reduced continuation or formation of new shell sites. Twaddle et al. (2017) studied stable isotope data from a shell midden in the southern Gulf of Carpentaria. Here they propose that the targeting of shellfish for the site was exclusive to the dry season when mobility is higher, as opposed to the difficulties that flooding presents during the wet season, and advocate it represents a targeting of a niche resource over a short-term occupation (Twaddle 2017:26–27).

Seasonality studies and isotopes

There have been many global in-depth studies of shell mound sites using oxygen isotopic techniques (Colonese et al. 2017; Dias et al. 2019; Eerkens et al. 2014; Hausmann and Meredith-Williams 2017; Jew et al. 2013, Jew and Fitzpatrick 2015; Leng and Pearce. 1999; Mannino et al. 2003; Milner et al. 2004; Voorhies et al. 2002). Equally there have been as many studies to develop sampling techniques to refine the estimates for past environmental reconstructions that can be also used for seasonality (e.g. Burchell et al. 2013; Jew et al. 2013, 2015). This section outlines the characteristics of oxygen, carbon, nitrogen and strontium isotopes, and how these can provide frameworks for migration, seasonality, occupation and environmental predictions.

Seasonality studies

A proportion of seasonality studies relied on historical observations and ethnographic accounts, or the presence of food processing events that have survived in the archaeological record and are known to only be available in that area at specific times/seasons e.g. remains of migratory animals or seasonal plant matter (Godfrey 1988:17). Complications arise when these materials are limited or absent, or the remains are available all year round to some extent, as is the case with most shellfish species. Isotopic analysis of these materials is becoming an increasingly important factor in determining the seasonality of these materials, more so as these techniques continue to be refined to provide more accurate estimates. Isotope values are typically recorded as a ratio difference between two isotopic weights of the same element (Adams 2019:233; Andrus 2011:2893; Godfrey 1988:17; Kennett and Voorhies 1996:694; Miyaji et al. 2010:110,115; Thompson et al. 2016:7). To fully integrate these values into seasonal, migration models one must first develop a baseline for the signatures of the corresponding isotope values naturally occurring between geographical zones or ecological and environmental conditions (Adams et al. 2019 234).

Sclerochronology

Sclerochronology is the analysis of the physical and chemical variations present in the deposits of hard tissue that, in the case of molluscs, form the shell and display daily, monthly and annual growth increments (Andrus 2011:2893; Buddemeier et al. 1974:196-197; Burchell et al. 2014:242; Leng and Lewis 2016:295; Richardson 1987:92). In a similar way to dendrochronology (Quitmyer and Jones 2012:135) the analysis of rings and bands of growth in shell can be used to identify environmental and climatic factors to which the shellfish was exposed.

Isotope analysis

Isotope analysis is used widely in archaeology. In human skeletal remains, it can be used to reconstruct diet and inform us on mobility patterns (Pate 1994). In marine settings, it can be used to reconstruct past environments, one example by analysing strontium and calcium (Sr/Ca), magnesium and calcium (Mg/Ca), and sodium and calcium (Na/Ca) ratios of corals to investigate temperature and pH of seawater (see Bell et al. 2017).

Isotopic analysis of shellfish coupled with sclerochronology and sampling techniques continues to refine the seasonal estimates of when shellfish were collected. Shell growth is governed by being submerged by water, salinity and sea surface temperature. As such, the conditions that form microgrowth lines are evident on the inner shell layer and can indicate sub-daily submersion/tidal influences. Additionally, the seasonal and annual growth evident in the outer shell layers can provide proxy environmental data on a daily scale for the life of the shell (Andrus 2011: 2893; Godfrey 1988:17; Mirzaei et al. 2014:459).

Stable oxygen isotope analysis refines this interpretation by evaluating the oxygen isotopes ratio (depicted as a delta (δ)^{18}O value) present in the aragonite structure of the shell or water. Oxygen isotopes are always present in water (Godfrey 1988:17), these values are measured as δ^{16}O/^{18}O ratios that are recorded in corals, ice cores, speleothems and carbonates such as molluscs. The values can be used as proxy palaeoenvironmental and climate data and to address questions of seasonality, for molluscs this can determine their season of death including when they were collected by people (Andrus 2011:2893; Bauwens et al. 2011; Kennett and Voorhies 1996:694; Leng and Lewis 2016:297). The oxygen ratio of water is not constant, it varies with sea water composition and changes in temperature which can be detected in the shell (Godfrey 1988:17; Kennett and Voorhies 1994:694; Leng and Lewis 2016:295). In an estuarine environment, fluctuations in seawater composition and temperature will be affected by air temperature, evaporation, tide, freshwater influx and precipitation. Isotopes are presented as Vienna PeeDee Belemnite (VPDB) values in units of parts per mille (‰). The heavier isotope is ^{18}O and the lighter is ^{16}O. The isotope ^{18}O will record more positive values indicating cooler temperatures, whereas ^{16}O will record more negative values and warmer temperatures (Fry 2006:22–23; Mannino et al. 2008:320). The highest δ^{18}O value recorded represents the coolest conditions experienced in the lifecycle of a shell, conversely, the lowest value will correspond with the warmest conditions. For every 4.34° C shift in temperature, δ^{18}O values will change by about 1‰ (Dettman et al. 1999; Goodwin et al. 2001).

Stable carbon isotope values for shell (depicted as a δ^{13}C value) are mainly derived from the water around it and the dissolved inorganic carbon (DIC) which also exist in water and shell. Shell δ^{13}C values can indicate contemporaneous carbon dioxide levels (CO_2) and water salinity though determining these values is more complex than for δ^{18}O shell values and prone to many variables that can obscure environmental signatures (Andrus 2011:2898; Burchell et al 2014:242–243; Culleton et al. 2009; Milano et al 2016:14–15). To this extent it is not uncommon for the δ^{13}C shell values to be omitted from seasonality or environmental reconstruction studies (see Godfrey 1988; Jew et al. 2013; Jolivet et al. 2015; Kennett and Voorhies 1996; Mannino et al. 2008).

Recrystallisation testing

Shell is a calcium carbonate structure consisting of the polymorphs aragonite and calcite. Aragonite, while less stable is the element required to successfully and accurately test for $\delta^{18}O$ values. A natural process known as recrystallisation occurs when the calcium carbonate structure of a shell is exposed to heat, and instigates a transfer from aragonite, to the more stable calcite (Claassen 1998:28; Loftus et al. 2015). The transfer is not homogenous, and care must be taken to ensure that when sampling, sections with a high rate of calcite are not selected (Jew and Fitzpatrick 2015:480).

There is debate about the validity of current sampling methods employed for recrystallisation testing. Some argue that the transfer from aragonite to calcite can begin almost immediately from when the shellfish is removed from a tidal habitat, regardless of exposure to cooking practices, and become almost undetectable within 1000 years. Proponents of the current method vehemently deny this accentuated timeframe and advocate that the current methods adequately navigate the sampling issues (Larsen 2015). If this transformation occurs, the heavier isotope ($\delta^{18}O$) are reset as the lighter ($\delta^{16}O$), eliminating their use for any isotopic interpretation (Andrus and Crowe 2002; Larsen 2015:2). How shellfish are cooked can directly impact the crystalline structure of shell, causing this transfer. Shellfish that are boiled or indirectly cooked are far less susceptible to recrystallisation than those cooked directly with flame or on embers (Larsen 2015:3).

Where to next?

A unifying thread through the Australian examples, save for the anthropological observations, is the development of models that rely on coarse data and a vague link used to form a new hypothesis. Inevitably, this is the case when there is limited supporting regional palaeoenvironmental data or archaeological data available. This is most evident in the clinal model where the assertion of shell matrix sites emerging with a northward regressing monsoon was based on an incorrect extrapolation of precipitation rates, not allowing for bias through preservation factors (Veitch 1999:55) and unverified mangrove placement with little other supporting data. However, for Weipa and the areas adjacent to Albatross Bay and the wider Cape York Peninsula, there has been an increase in archaeological research (student and academic) associated with these and associated sites in the past ten years (e.g. Cochrane 2014; Holdaway et al. 2017; McNaughton et al. 2016; Morrison 2013a, 2013b, 2014, 2015, 2018; Morrison et al. 2015).

New technical methods are constantly being advanced for seasonality studies using the stable oxygen isotope and sclerochronological analyses. This potentially allows for the detection of individual seasons and phases of mound formation by determining the season of capture for individual shellfish. This can be used to provide insight into short-term occupation records. Seasonality studies have been largely overlooked in favour of questions regarding palaeoclimate variability and the cause of broad chronological trends. Determining seasonality offers an insight into the smaller scale formation of shell matrix sites as well as determining patterns of general shellfishing behaviours that directly illuminate social behaviours, occupation and subsistence patterns of the people who dwelt there.

CHAPTER 3 STUDY AREA

Prunung

Prunung is a prominent place within Thanakwithi Country (Fletcher 2007), an area approximately 7 kilometres north of Weipa in western Cape York Peninsula, far north Queensland (Figures 2, 3). Prunung is a low beach ridge with two aspects situated along the northern bank of Mission River, one of the largest of the four rivers that flow into Albatross Bay and out into the eastern waters of the Gulf of Carpentaria. The beach aspects run east to west, peaking in the south (Morrison 2013b, 2015; Stone 1995). The east face extends approximately 550 m and is marked by narrow mud flats before being cut by a deep tidal channel, Prunung Creek (also known as Andoom Creek). On the other side of the channel, the mud flats are much wider. The west beach features wide, shallow tidal sand flats that extend for approximately 400 m.

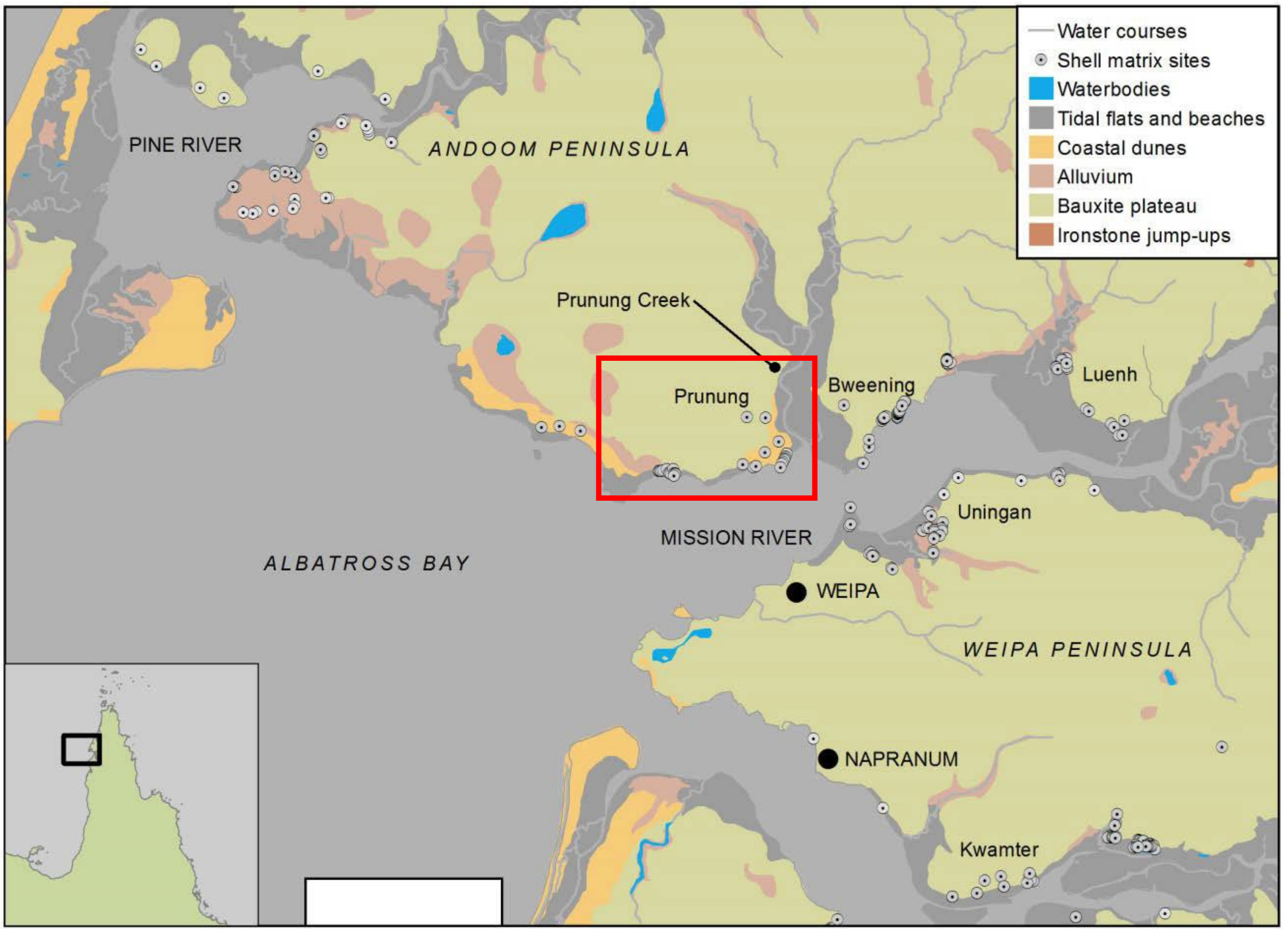

Figure 2 Location of Prunung and associated shell matrix sites in northern Albatross Bay (From Morrison 2013b:166). Highlight added.

The low Prunung beach ridge abuts a bauxite plateau which holds some of the richest deposits of this mineral in Australia. As such, much of the Weipa region is leased by mining company Rio Tinto, who operate Australia's highest-grade bauxite mine, a shallow deposit with low silica content (Geoscience Australia 2017). In part, it has been a combination of the early geological mineral explorations into Cape York Peninsula and continual expansionist practices of mining activities that has led to the identification, recording and analysis of the prolific shell mound matrix deposits throughout the region. However, these same practices have led to the irreversible damage and destruction of many of these sites, including the mechanical harvesting of these sites in order to use the shell for road and rail base (Ernest Douglas Snr pers. comm. 2013) Prunung is the location of 12 shell matrix sites, predominantly mounds. It is also a popular fishing location and the impact of regular vehicle use across the beach ridge and to the shell matrix sites is readily visible (Morrison 2015:3).

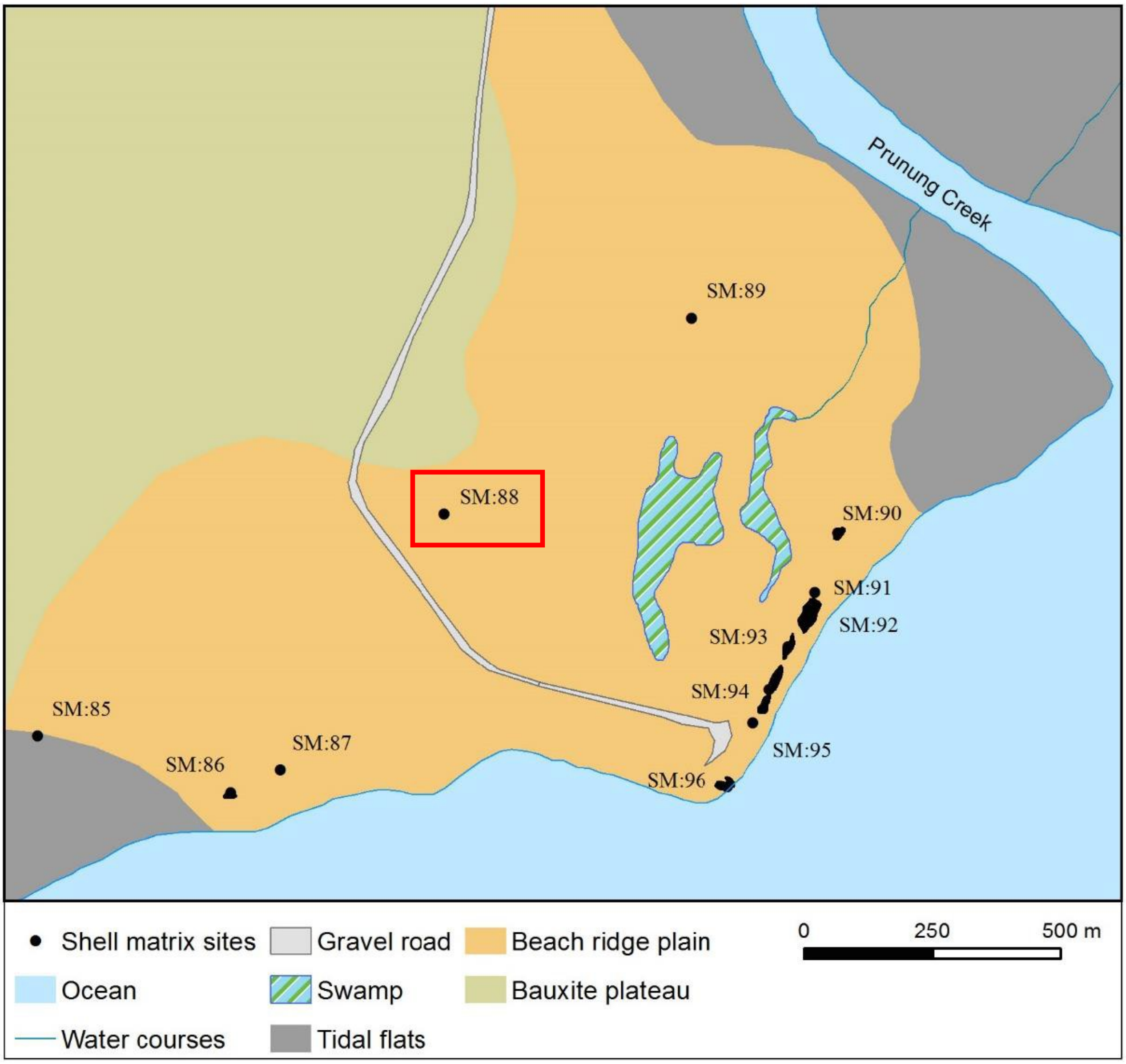

Figure 3 Prunung study area showing shell matrix sites, SM:88 shown in highlight (after Morrison 2015:2).

Previous research

Archaeological research near Albatross Bay began with the work of Richard Wright (1971) and his field work in locating and investigating the origins of shell mounds. Bailey (1975, 1977, 1993, 1999) provided the first models for considering the function and formation of these mounds, namely that they were seasonal camps for small groups, possibly family, who would exploit the glut of shellfish and other resources during the wet season. Cribb (1986) recorded them as story places (1986:145) that tied them to previous camp bases, even though that use did not remain within living memory of the present community. Cribb also posited that these were consumption sites, where seeds would be naturally or deliberately deposited and over time provide shade in otherwise harsh conditions that would in term attract people back for comfort thereby creating a ‘feedback loop’ (1986:148). Cribb viewed mounds as temporary camps for exploitation coastal resources.

Stone (1991, 1995) found the distribution of large shell mounds with the mounds built by Scrubfowl too coincidental to not be connected. Stone noted the many similarities between the mounds archaeologists deemed anthropogenic and those built by the Scrubfowl. This began a new wave of shell mound investigation, particularly by Bailey (1991,1994) and (Cribb 1991) to ascertain the difference between naturally occurring and anthropogenic mounds which included identifiable stratigraphic layers, and the presence of a variety of food stuffs and artefacts. Stone argued that claims of these sites being cultural were based on the misunderstanding of historical records, such as by (Roth 1901) who noted seeing people camping and cooking atop of them (Stone 1995:80). Rather, Stone interpreted this to mean people exploited an existing natural feature for occupation or use. Stone’s argument has been widely discredited (Bailey 1991, 1994, Cribb 1991)

Other studies have investigated the location of shell mounds in relation to ecological and geological zones and varying substrates (Morrison 2013a) and site variability between shell mounds (Holdaway et al. 2017), understanding the difference or chronology of mound building behaviour including the progression from scatter to mound (Morrison 2013b) or refining techniques for analysing the content of shell mounds to reduce the bias resulting to the visual dominance of some species (e.g. the robust nature and weight of *T. granosa*).

There have been no archaeological studies focusing on seasonality in the Weipa region, or that of Albatross Bay. Bailey (1977) and Morrison (2013a) offer the most comprehensive models that address this problem but these are based on historical observation and ethnography, which while convincing have no quantitative framework against which to support them. Basing models on ethnographic or historical data for societies millennia in the past is fraught and is often discouraged or deemed ‘inappropriate’ (Faulkner 2013:2). However, they provide an equal but alternative framework to studies that look to the changes noted in environment and climate studies as the driving forces for shifts in human mobility, subsistence and technological.

The SM:88 shell mound

Description

This research focuses on one of the seven shell mounds excavated at Prunung in 2003 and 2004 by Morrison (2010). SM:88 was identified at the conclusion of the final field season, and consequently was excavated in a very short timeframe (Morrison 2010:273). SM:88 is a low shell mound with a height of 75 cm and maximum diameter of 18 m. Situated 800 m from the main cluster of shell matrix sites, SM:88 is located approximately 450 m north of the current shoreline, on a narrow sand ridge between a seasonal swamp and the edge of the bauxite plateau. Although one section of approximately 3–4 m of the mound structure had been impacted through recent quarrying events, the remainder of the shell mound was undisturbed.

Excavation, composition and age determinations

The excavation of SM:88 was carried out on an undisturbed section of the mound as a 50 x 50 cm pit to a depth of 75–80 cm, over seven levels ranging between depths of 7–12 cm. (XU). The stratigraphy was comprised of three layers, two of which were considered anthropogenic (Table 2). Layers A and B included whole and fragmented shell of *T. granosa* and *M. hiantina*. which tapered off substantially in layer C as it reached the natural substrate. Layer C had a similar signature to the surrounding sediment off the shell mound that largely consisted of a fine grained, sandy sediment with large bauxite pisolith inclusions and few ironstone < 30 mm in size (Morrison 2010:273). The soil in layer B was dark. The soil in layer A was not as dark as the soil in layer B and contained small divisions of root and other humic material (Table 2).

Layer	Depth cm	Description
A	15	Whole and fragmented shell valves, humic material, rootlets
B	45–50	Larger volume of both whole shell and a darker soil to Layer A
C	15	Fine sandy sediment, large inclusions of bauxite pisolith, minimal shell, natural substrate

Table 2 Description of broad stratigraphic layers, SM:88 (Morrison 2010:273).

Two shell samples were sent for age determinations, and results calibrated with CALIB version 6.10 at 1σ using the SHCAL and Marine13 calibration datasets (Hogg et al. 2013; Hughen et al. 2004; Reimer et al. 2013), an appropriate marine reservoir correction factor applied (Morrison 2010:379–381). Samples were collected at depths of 65 cm, towards the base of layer C, and at 21 cm below the surface of layer B. The upper age determination required AMS measurement as the sample size was quite small with parts of the shell deemed unsuitable due to recrystallisation. The ages retrieved were 289–463 cal BP (Wk14508) and 431–560 cal BP (Wk14509) (Morrison 2015:5,7). The upper age (Wk14508) would have marked the interface between XU2–XU3, indicating a very conservative estimated cessation mark of SM:88. The lower age (Wk14509) would correspond with the basal section of the final level, XU07, indicating when the mound formation for SM:88 began (Table 3).

	Units	XU 1	XU 2	XU 3	XU 4	XU 5	XU 6	XU 7
Mean depth	(cm)	7.27	11.78	11.95	10.22	9.23	9.52	7.28
Gross weight	(g)	21700	24400	24500	24900	26000	27500	16000
6 mm residue	(g)	9455	8601	8168	8555	9727	7012	3452
2 mm residue	(g)	3000	3700	3500	3500	3400	2500	6500
Soil	(g)	9245	12099	12832	12845	12873	17988	6048
Stones/rocks	(g)	495	205	130	130	400	405	655
Age determination	(n=2)	0	0	Wk14508	0	0	0	Wk14509

Table 3 Summary of stratigraphy, sediment and age determinations, SM:88 adapted from Morrison (2010:274)

Shellfish, non-molluscan material and artefacts

During the initial inspection and excavation process, the mound was thought to be dominated by *T. granosa*, however after thorough laboratory analysis was conducted it was determined that in fact *M. hiantina* was the dominant shellfish throughout all levels, though sometime only to a small degree (Table 4, Figure 4), (Morrison 2010:275). Small numbers of non-molluscan fauna were also retrieved from the 6 mm samples (Table 5)

		XU 1	XU 2	XU 3	XU 4	XU 5	XU 6	XU7
Anadara granosa	MNI sample	28.7	97.4	125.3	84.3	92.3	58.2	8.9
	MNI - %	42.7	34.0	41.0	47.7	44.5	27.8	34.4
Marcia hiantina	MNI sample	29	174	157	85	101	125	14
	MNI - %	43.2	60.8	51.2	47.8	48.7	59.6	54.0
All other species	MNI sample	10	15	24	8	14	27	3
	MNI - %	14.1	5.2	7.8	4.5	6.8	12.6	11.6

Table 4 Shellfish MNI data, SM:88 (From Morrison 2010:276)

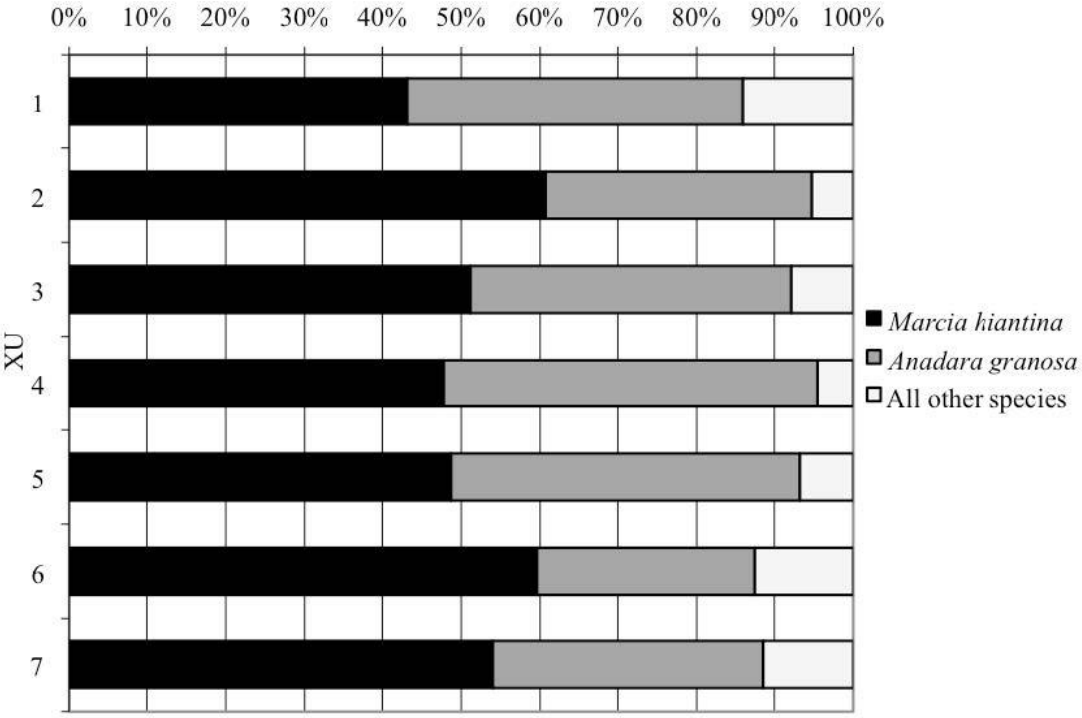

Figure 4 Shellfish MNI as proportion of total XU MNI, SM:88 (Morrison 2010:277)

	Unit	XU 1	XU 2	XU 3	XU 4	XU 5	XU 6	XU 7
Silcrete: Broken flake	(n=1)	1	0	0	0	0	0	0
Milky quartz: Broken flake	(n=1)	0	1	0	0	0	0	0
Quartz: Angular fragment	(n=1)	0	0	0	1	0	0	0
Otolith	(n=1)	0	0	0	1	0	0	0
Crab fragment	(g)	0	5	5	5	5	1	0
Other bone	(g)	0	5	2	3	4	0	0

Table 5 recovered artefacts and non-molluscan fauna by XU, SM:88 (after Morrison 2010:277–278)

Modern climate and environment

Weipa is approximately 250 km from the northernmost section of Cape York Peninsula, and lies within both the tropical and equatorial climate zones. Weipa has a traditional monsoonal, wet-dry season cycle. It experiences an annual rainfall of ~2 m, the majority falling in the wet/summer season between December and March, with April to November being the dry/winter season (Figure 6). The annual rainfall has increased by ~150 mm over the 30-year period 1989–2018 (1872 mm), compared with 1959–1988 (1712 mm) (BOM 2019:3). Average daily temperatures range between 31–35°C with the slightly higher temperatures typically occurring in late spring when there is a build up to the onset of the wet season (Figure 5). Average, maximum and minimum annual temperatures between 1959 and 1994 were 32.3, 38.4 and 23.9°C respectively. This records a less than 2°C variance to the same temperatures records for 1992 to 2017 when the average, maximum and minimum temperatures were 32.8, 39.2 and 21.9°C (BOM 2017; Taylor et al. 2008:3).

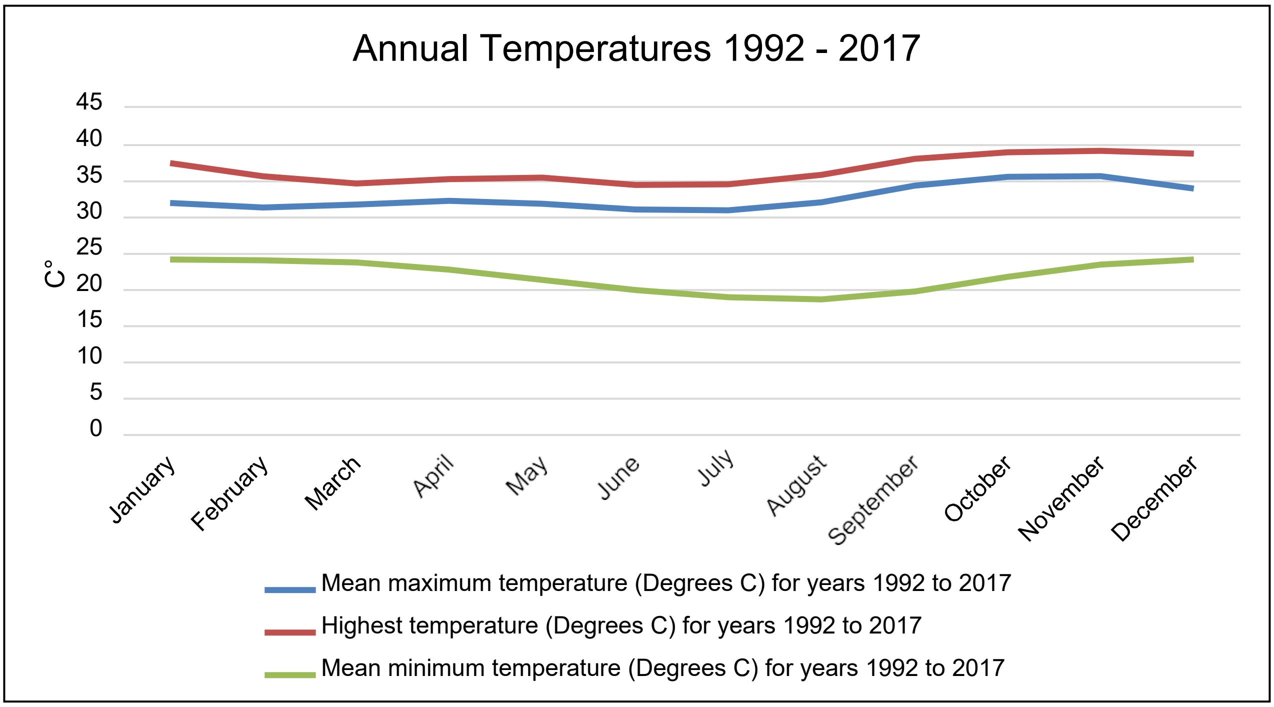

Figure 5 Averaged monthly temperatures for Weipa between 1992–2017 (BOM Climate Statistics 1992–2017)

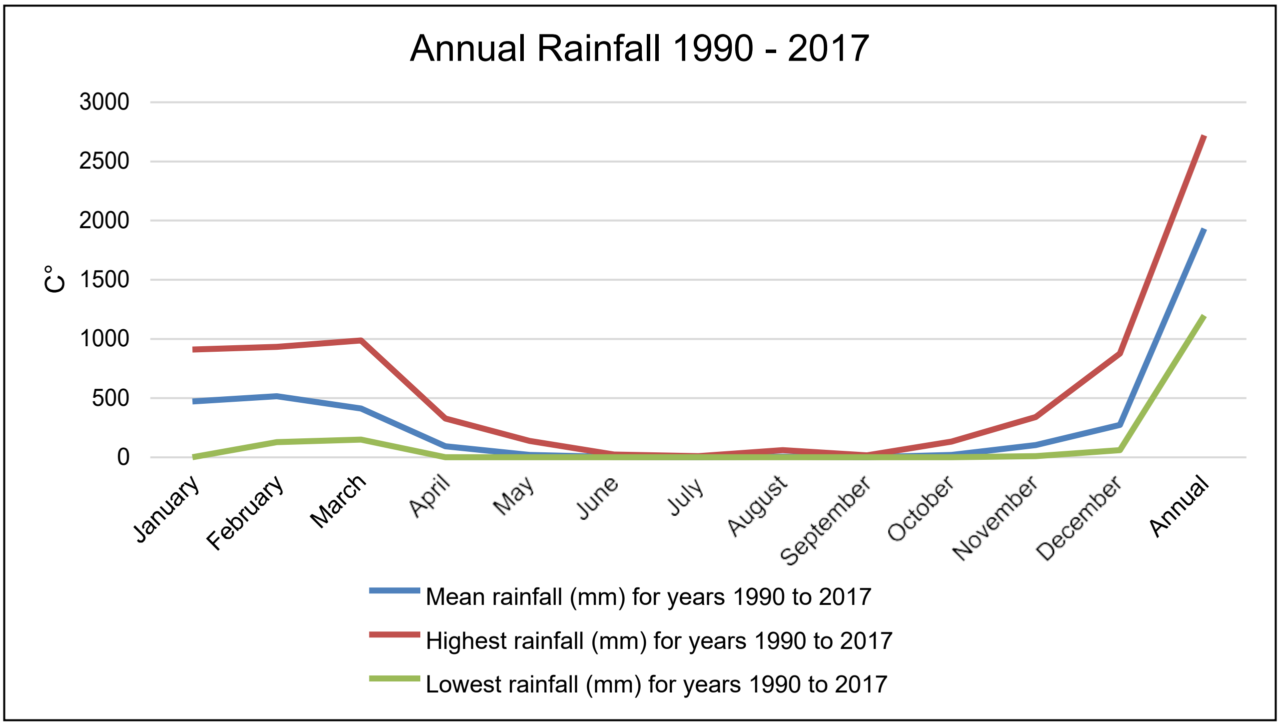

Figure 6 Averaged monthly rainfall for Weipa between 1992–2017 (BOM Climate Statistics 1992–2017)

Sea surface temperatures (SST) in oceans around Australia have experienced an increased rate of warming over the past century. Between 1910 and 1929 the SST was 0.68°C cooler than between 1992 and 2011, slightly lower than the global SST increase of 0.71°C. Since 1910, when records of SST began, 75% of the warmest temperatures occurred after 1992 (Lough et al. 2012). The modern specimens of *M. hiantina* were collected in April and October 2003. SST trends depicting annual and monthly averages, and SST ranges for April and October are compiled from data spanning 1998–2015 in Weipa (Figure 77, 8 and 9). Temperatures were recorded in 1998 and 2002 at multiple depth locations and were taken at 30-minute intervals, daily. Sediment temperatures are typically only slightly lower than SST and the variation between the monthly data for April and October at a depth of 5 m to that at 0 m was 0.26°C, the minimum temperatures reached differed by 0.25°C and the maximum temperatures by 0.36°C. (Afiati 1994:57; BOM 1998; 2005; 2016).

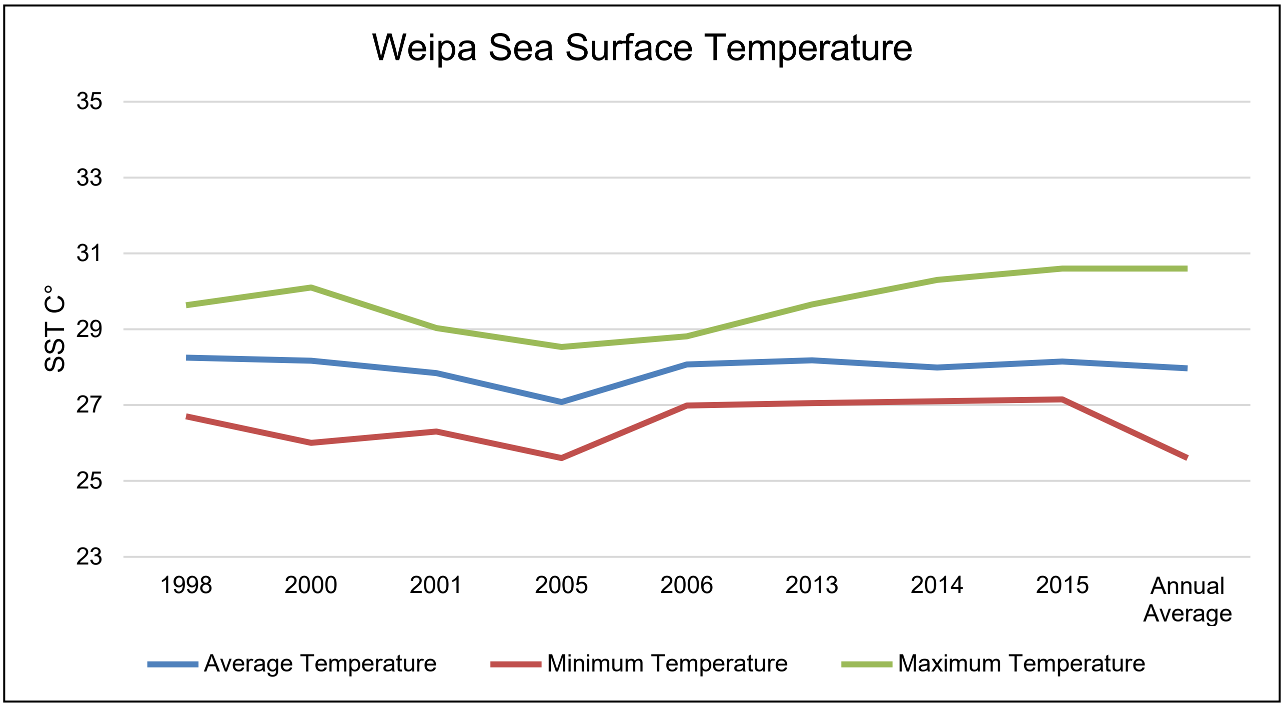

Figure 7 Averaged annual sea surface temperatures for Weipa between 1998–2015 (BOM Climate Statistics 1992–2017)

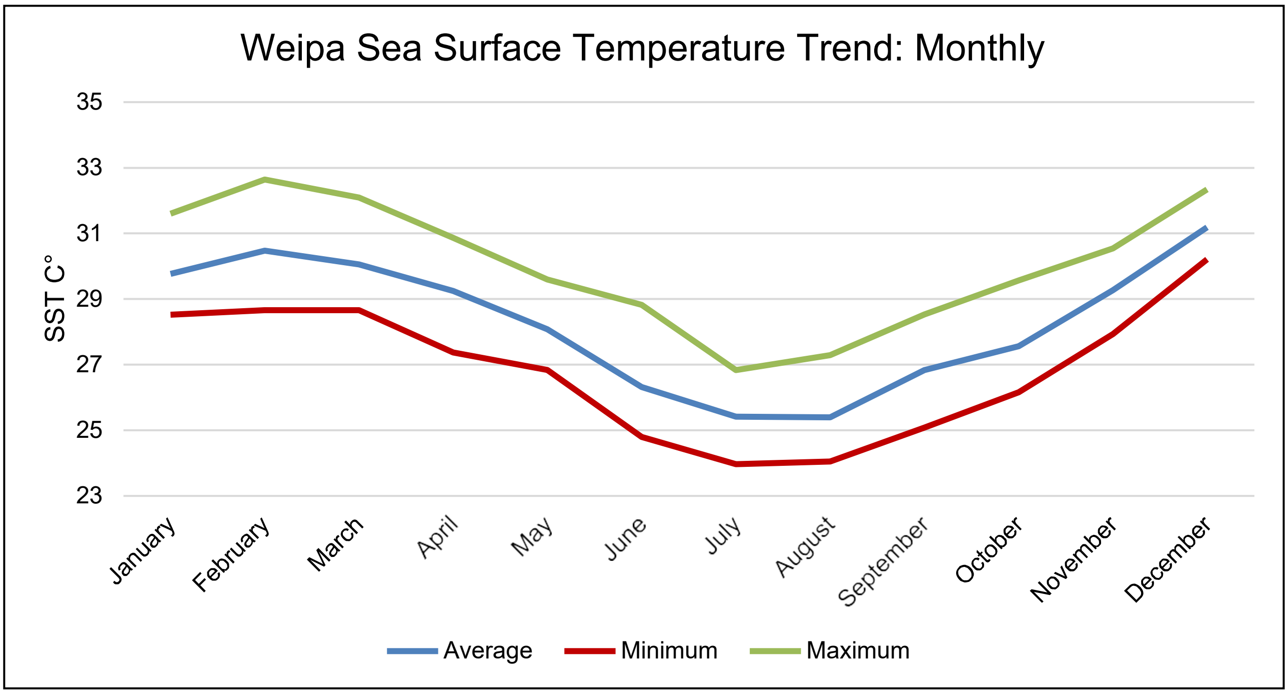

Figure 8 Averaged monthly sea surface temperatures for Weipa between 1998–2015 (BOM Climate Statistics 1992–2017)

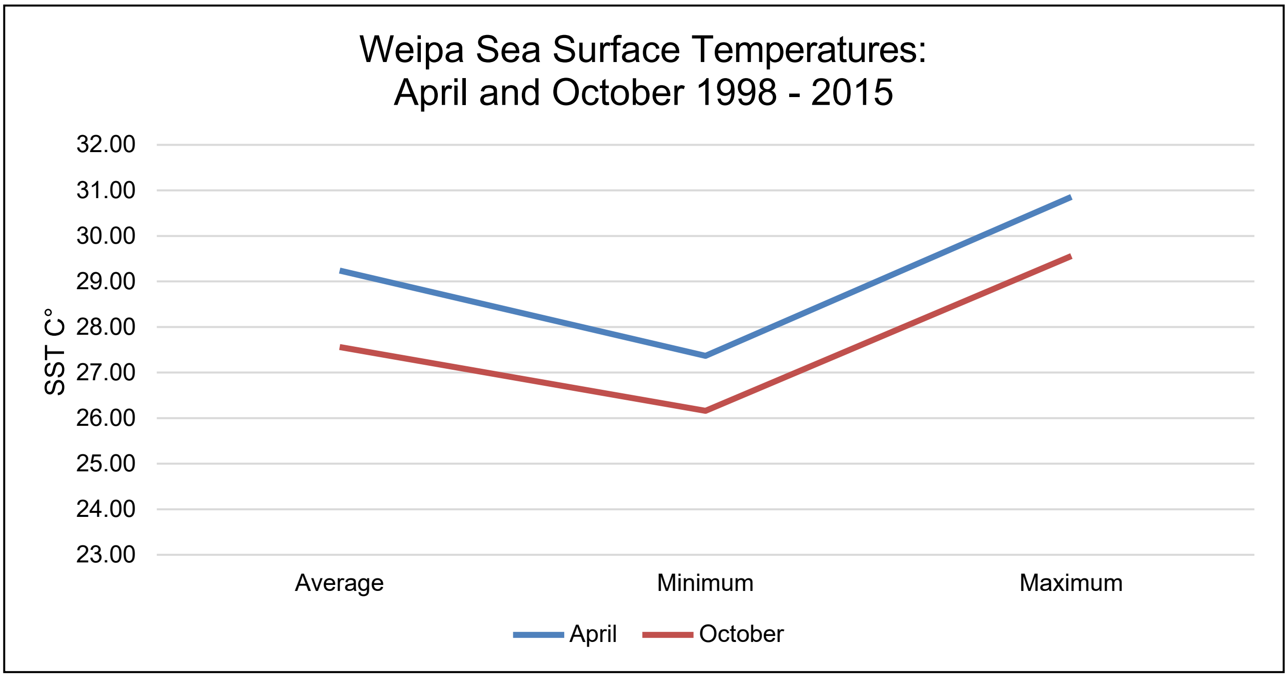

Figure 9 Averaged monthly sea surface temperatures for April and October, Weipa between 1998–2015 (BOM Climate Statistics 1992–2017)

The dominant species of vegetation is *Eucalyptus tetrodonta* or Darwin stringybark (also known as Messmate), making up a large proportion of open woodland ecosystems that occur on the Weipa bauxite plateau. The distribution of this tree species is not dissimilar to the distribution of shell mound matrix sites, in that it largely traces the tropical coastline of northern Australia, so the two features are often co-located (Specht 2012:4; Slee et al. 2015). *Melaleuca* spp. and what is commonly referred to as monsoon or dry notophyll vine forests also regularly punctuate the landscape (Godwin 1985; Morrison et al. 2018; Shiner et al. 2013:65; Specht 1977 Stevenson et al 2015:19; Stone 1995:95; Taylor et al. 2008:11).

Past climate and environment

At c. 4500 BP, the global and regional trends for climate were of heightened variability, with increased aridity becoming apparent at c. 3500 BP, as well as seasonality with a marked decrease in overall precipitation of up to 300 mm annually (Andrus and Thompson 2012; Berger et al. 2013; Bourke 2003:42; Bourke et al. 2007:91, 93; Brockwell et al 2013:21; Faulkner 2009:824; Haberle and David 2004:169; Morrison 2013a:89; Rowland 1999:146; Shulmeister and Lees 1995:13). The seasons became more markedly separated between the monsoonal, or wet season, from December to March The dry season is approximately from April to November, with a peak June–September, with the latter experiencing minimal rainfall (Turney and Hobbs 2006:1744). Significant variations existed within regional and local contexts, conditions becoming more unreliable with the monsoon regression: some areas could have increased precipitation one year, followed by a significant decrease the year after (Shulmeister and Lees 1995:15). El Niño events peaked c. 3000–1000 BP and were marked by more frequent drought, frost and unpredictable occurrences of torrential rainfall events (Haberle and David 2004:169; Shulmeister and Lees 1995:12). Recent stable oxygen isotope studies in the Northern Territory have indicated a secondary decline in monsoonal rain c. 2000–500 BP with a brief increase in precipitation c. 1200 BP and an ENSO event that has been linked to a decline in mudflats c. 800–500 BP (Brockwell et al. 2013:22, 29). In northern Western Australia, despite the overall greater aridity, periods of higher rainfall were detected at c. 3500–2800 BP, 2100–1600 BP and post–1000 BP (Veitch 1999:55). In Weipa, hydrological data has shown an event of peaked aridity c. 1000 BP (Beresford 2011; Stevenson et al. 2015:24).

The development of mangrove fringes and mudflats during the mid–late Holocene provided the habitat for shellfish beds such as *T. granosa.* The seaward retreat of mangroves c. 4000 BP is often correlated with the human exploitation of *T. granosa.* (Bourke et al. 2007:93). In many coastal areas, mangroves are thought to have disappeared during the mid-Holocene (O'Connor 1999:40; Rowe 2007:98–99), though a resurgence has been recorded in the Northern Territory c. 700–500 BP (Brockwell et al. 2013:22).

Following the Last Glacial Maximum (LGM) the climate and environment were punctuated by episodes of significant variability (Fredericksen et al. 2005; Haberle and David 2004; Shulmeister and Lees 1995; Turney and Hobbs 2006). Arguably, the most notable of these for the mid–late Holocene were the rise and subsequent stabilisation of sea levels c. 6000 BP and the onset of the El Niño Southern Oscillation cycle (ENSO) c. 4000 BP (Faulkner 2008:86; Shulmeister and Lees1995:13–14). Sea level rise had a multitude of effects, including the formation of chenier plains, the infilling of bays and the seaward progradation of shorelines (Beaton 1985:5; Bourke 2003:43; Carter et al. 1999:96; Shiner et al. 2013:69; Shulmeister and Hobbs 1995:10). The progradation of the northern Australian coastline occurred in a series of phases (Woodroffe et al. 1985). Brockwell et al (2009:60–61), in relative agreement with Faulkner (2009:823; 2013:24), Fredericksen et al. (2005:3), Hiscock (1999:91–93), and Woodroffe (1994, 2018) determine these phases to have occurred over approximately 8000 years. Calibrated with CALIB 5.0.1 at 2σ using the marine 04.14c calibration curve and an appropriate marine reservoir correction factor applied, these phases are outline as:

- Transgressive phase (10000 – 6000 BP): tidal incursion and landward extension of mangrove forests in a prior valley;
- Big Swamp phase (6000 – 4000 BP): mangrove forests established throughout the estuarine plains;
- Sinuous/Transition phase (approximately 4000 – 2000 BP): mangrove forests eliminated, tidal flows confined to channels, freshwater vegetation established on the plains; and
- Cuspate/Early Freshwater phase (2000 BP – present): current freshwater wetland systems and extensive saltflats.

These phases belong to averaged global and regional (northern Australia) trends and should not be extrapolated to explain localised conditions, as they are known to vary widely and often work in opposition to these broader patterns (Haberle and David 2004:169; Ward et al. 2015; Woodroofe 2018). Rowland (1999:143, 149) notes such a variation along the Great Barrier Reef with sea levels being 4 m higher at c. 4000 BP and settling to modern levels c. 2000 BP and in north Queensland seas maintaining at higher level of 1–2 m c. 6000 BP than present (see also Shiner et al. 2013:69) Rowland (1999:149) also notes that the progradation of estuaries in Albatross Bay only occurred post-3000 BP.

Biology of bivalve molluscs: Tegillarca granosa and Marcia hiantina

Until recently, the majority of shell mounds in northern Australia record *Tegillarca granosa* (previously named *Anadara granosa*) as forming up to 90% of their composition by weight and volume (Bailey et al. 1994:69; Bourke 2005:30; Morrison 2003:2, 2013a78; O'Connor 1999:47;). More recently, as field-based research has developed new datasets, a greater range of sub-species have been detected and an overall decrease (and occasional complete absence) of *T. granosa* has been noted. Along with *T. granosa, M. hiantina* is the most common mollusc present. As such the biology of both is presented here, though there is little published research relating to *M. hiantina*.

Figure 10 *T. granosa* (Linnaeus, 1758) and *M. hiantina* (Lamarck, 1818) (Natural History Museum Rotterdam, reproduced in http://www.marinespecies.org)

For abiotic factors, optimal abundance for these molluscs require a soft, fine muddy substrate at an elevation between the high and low water neap tide marks, with a water content of 55–65% and high organic content (Afiati 1994:47, 234; Broom 1985:4–5). Shell bed density diminishes with depth and is prone to greater stress when subjected to large tidal ranges and exposure from high elevations. Thus, mid-tide level is ideal, though T. granosa does produce high density beds in the soft intertidal zones bordering mangrove swamps, in particular those with a sediment depth of 0.5–1 m that are protected from overly turbid wave energy (Afiati 1994:46–7,85; Beaton 1985:13; Broom 1982b:135; 1985:1,4–5; Endang et al. 2016:778–780; Khali 2017:75; Kithsiri 2000:27; Mirzaei et al. 2014:459,464; Morrison 2003:2; Oon 1986:1–2; Shiner et al. 2013:65; Tookwinas 1985:2–3). *T. granosa* prefer areas with a freshwater influence, such as estuaries within a bay that provide some protection while ensuring a nutrient source following rain events through runoff (Broom 1985:7; Tookwinas 1985:3). Temperature and salinity are a primary influencer on shellfish abundance. Peak growth rates and abundance occur when salinity is within 5–35% and sea surface temperatures (SST) are between 28.8 and 31.5°C (Afiata 1994:57; Broom 1985:76; Endang et al. 2016:777–778;

Kithsiri et al. 2000:27; Kithsiri et al. 2004:14; Miyaji et al. 2010:115; Tookwinas 1985:3). During the wet season, heavy rainfall and associated runoff dilute the salinity content of the water resulting in the depletion of communities, particularly mature individuals, positioned near river mouths. While juveniles can withstand lower salinity rates, salinity levels usually revert to more sustainable levels within two weeks. The final abiotic factor is oxygen. Older individuals (more than juveniles) can withstand periodic reductions in oxygen content caused by increased temperatures during the day, especially in higher elevation, during high tides or an influx of rainwater and runoff. Oxygen saturation levels of ~15% will see a reduction in the population of ≥50%, with lower levels than that resulting in death of the entire population (Afiata 1994:64; Broom 1985:8).

Biotic factors include feeding and predators. *T. granosa* have short siphons and therefore do not burrow to the same depths as other marine bivalves; they are considered to be surface deposit feeders. *M. hiantina* have well developed, long siphons which allow deeper burrowing and feeding in water with higher solidity content. However, periods of higher turbidity that increase the suspended sediment content negatively impact both species (Afiati 1994:4; Broom 1982b:140; Broom 1985:8–9; Sartori et al. 2008:115–116; Tookwinas 1985:3). Both are detritus and benthic microalgae feeders. Seagrass directly increases the organic content in water and thereby increases the abundance of a bivalve population (Kithsiri 2000:27). Both bivalves will be the dominant biomass in their location and often there will be no significant animal present to compete for the same food source (Afiata 1994:56; Broom 1982b:138, 1985:10–12). Interestingly, density does not contribute to mortality rates, but is thought to impact growth rates (Broom 1983:392). The factors that do impact mortality are periods of heightened rainfall and associated turbidity and runoff which can reduce a population by 20–50%. Populations at higher elevation in the shoreline face greater risk from predators such as wading birds and other marine fauna (gastropods, starfish etc.). In these situations, *T. granosa* will more likely lodge themselves deeper in the mudflat. Rises in water temperature from 21°C to 27/28°C contribute to mortality increase (Beaton 1985:9; Broom 1982a:76, 1982b:140, 1985:18–20; Clune and Harrison 1999:73; Kithsiri et al. 2004:28; Meehan 1982; Morrison 2003:2; Shiner et al. 2013:69). However, this susceptibility is limited, as it is also extensively recorded that *T. granosa* is quick to recover and will relocate or reappear in areas along a coastline with less detrimental conditions to their growth and mortality, whereas *M. hiantina* is potentially more prone to the effects of overharvesting. *T. granosa* also has a higher reproductive rate than other marine bivalves which likely contributes to the population's rapid recovery (Broom 1983:389; Kithsiri et al. 2004:28; Meehan 1982;

Morrison 2003:2).

Neither species are hermaphrodite but have distinct and equal division of sexes once they reach a size of >25–30 mm. While there is some level of spawning throughout the year, both have major spawning seasons during the transition from wet to dry season; there is some speculation this relates to the decrease in salinity content (Afiata 1994:88; Broom 1985:23–24; Khali 2017:86).

The final biotic factor is growth which in terms of shellfish biology is considered more important than age. Size and growth rate are not necessarily reliable indicators of age as average growth rates on modern specimens can vary according to region (latitude) and situation (e.g. those located by the mouth of a river grow at a slower rate to those within an estuary) and these variations will be more pronounced over long periods of time. Bivalves display regular growth phases, from daily and lunar growth lines within the shell structure, to seasonal rings and bands evident on the shell exterior (Broom 1983:393, 1985:14–17; Mirzaei et al. 2015: 6; Randklev et al.2009:206). However, growth bands are often difficult to identify and count in the first annual cycle of growth (Mirzaei et al. 2015:1–2). There is no uniform curve to growth rates for either bivalve. *T. granosa* has been known to grow 4–5 mm in the first six months and achieve 18–32 mm within two years. Some record mature sizes of 63 mm, but most are ~54 mm. The typical lifespan for *T. granosa* is <3 years (Broom 1985:14–17; Mirzaei et al. 2015:8; Tookwinas 1985:8).

Summary

The climate data indicates that while there is little seasonal temperature variation (Figure 5), there is a distinct increase in precipitation events during the wet season (Figure 6). The increased rainfall of the wet season creates an influx of freshwater runoff into estuaries, reducing seawater salinity and temperature. The isotopic values should therefore capture these distinct seasonal signals, with lighter values for the dry season and heavier values for the wet season.

CHAPTER 4 METHODS AND MATERIALS

The materials and methods detailed in this chapter include specimen selection requirements for modern and archaeological shell, recrystallisation testing, sample preparation, sampling strategy and isotopic analysis. The excavation of specimens used here was conducted separately to this project, and is outlined in Chapter 3.

Modern specimens

In April 2003 and on 18 October 2003, a *Nggoth* elder, the late Mrs Aileen Heinemann, collected modern specimens of *M. hiantina* near Napranum at a place called Munding. These were provided to Morrison at the time as part of ethnoarchaeological research on shellfish use in the community. These specimens were cooked by boiling in saltwater, and the shells provided after the animal had been eaten. Each of the sample bags have been stored in controlled conditions along with other field samples since this time. The two modern specimens were assigned a label with the prefix MA and a corresponding number to indicate the month they were collected. MA indicated these were modern alternatives to the archaeological shell, meaning MA04 correlated with the modern shell collected in April, and MA10 correlated with the modern shell collected in October.

MA04 was collected in April 2003 marking the start of the dry season, and MA10 was collected in mid October 2003 marking the transition from dry to wet season. These modern specimens provided a control, or baseline, for the values generated from the archaeological shell.

Sample selection

The initial selection process for both modern and archaeological shell was based on a widely accepted selection of methods (see Burchell et al. 2013a:262, 2013b:629; Jew et al. 2013:176, 2015:4798–479; Kennett and Voorhies1996:697). Whole or near-whole shell with an unbroken line in the direction of growth from umbo, or near umbo, was selected ensuring that the ventral/terminal margin was intact. Shell with visible evidence of burning was disregarded, which reduces the chances of selecting shell with concentrations of calcite present as a result of recrystallisation triggered by excessive heat. Shell with an undamaged outer layer of shell was preferred as when this layer is damaged or absent it can indicate that diagenically changes have occurred, either from heat or pressure from being buried.

Two archaeological shells from each of the seven XUs from SM:88 were selected, with two exceptions. For the XU01 and XU07 only one shell was selected. The number of suitable shells for these two levels were far lower than those from the intermediate levels. XU07 in total had two whole or nearly whole shells, one of which had visible damage to the outer layer of shell. This is possibly a result from being on the basal layer of the SM:88 that was situated in an area prone to low level flooding in the wet season. The issue with the shell from XU01 was one of fragmentation. The number of broken shells versus shells with a continuous and undamaged line from umbo to terminal margin compared with other XUs was disproportionate. Given this was the surface level of SM:88 it is suspected trampling was a contributing factor. One modern shell from each season was also selected. All the selected shells were weighed and then measured from umbo to ventral margin and for width. Each shell was then rinsed with reverse osmosis deionised water (DI), and scrubbed with a stiff bristle brush to remove any remaining mound soil or loose periostracum. The shells were placed in a drying oven at room ambient temperature (<30° C) for two days to ensure they had thoroughly dried.

Recrystallisation testing

The two most widely used techniques in testing for recrystallisation are the use of Fourier-transform infrared spectroscopy (FTIR) or X-ray diffraction analysis (XRD) (Burchell et al. 2013:262; Jew and Fitzpatrick 2015:478; Monnier 2018:809) using a Bruker XRD with cobalt X-ray source which has both K alpha1 and alpha2. The usual standardised methods were employed for analysing each shell for the presence of calcite and aragonite. While some methods crush a whole shell or percentage of shells for each XU and extrapolate the results across that level, there were not enough viable specimens to contemplate this option for SM:88. To allow for the heterogenous nature of the shell structure, powdered samples were scraped, using a surgical scalpel, from multiple spots on the outer layer of each shell and along the ventral margin. The scalpel was cleaned thoroughly and wiped with acetone after each shell. The powder was placed onto a silicon wafer, a drop of acetone was added to adhere the powder to the wafer before being placed in the XRD for analysis. Bruker software suite DIFFRAC.EVA was used to interpret the results against calibrated studies and exported as. xy files before converting them to Excel (example of two runs Appendix 1)

Sample preparation

Seven of the archaeological shell were etched in a dilute 10% hydrochloric bath (HCL), to remove any diagenically altered carbonate (Kennett and Voorhies 1996:697; Jew et al. 2013:174). Each shell directly corresponded to one of the seven excavated XUs in SM:88. They were then rinsed repeatedly under DI water before being placed in a drying oven again for a further two days at room ambient temperature to ensure they dried thoroughly. These shells were assigned a label with a prefix EA and corresponding XU number. EA indicated that they were an etched archaeological shell, meaning EA01 was an etched archaeological shell from XU01, EA02 was an etched shell from XU02, and so forth.

The remaining shell included were not subjected to etching. The five non-etched archaeological shell were assigned a label with the prefix A and a corresponding XU number. The prefix A indicated they were an archaeological shell that had not been subjected to etching. A02 indicated the archaeological shell was from XU02. There were no A01 or A07 that related to XU01 or XU07. The two strategies were employed to test whether etching in HCL does increase the purity of the sample and produce more accurate results. One element that was not tested for was whether HCL has an impact on the recrystallisation process in any way.

Sampling strategy

Irrespective of the differences in preparing the samples, the sampling strategy from this point in the process was the same across all shell. While many oxygen isotope studies advocate for specimens to be cross-sectioned, mounted in epoxy resin and micro-milled, this primarily benefits environmental reconstructions that focus on changes recorded across the lifespan of the specimen. Seasonality target the values held in the terminal margin (Burchell 2013; Spötl and Mattey 2006). The terminal margin value alone is not adequate for determining seasonality and the standard is that the more samples taken along the growth line from the terminal margin to umbo the better as this allows for a cross checking in the validity of results (Jew et al. 2013; Jew and Fitzpatrick 2015; Twaddle 2016:130).

Spot sampling was performed using a Dremel 3000 Rotary Tool and a diamond cylinder point. Samples were taken at the terminal margin (TM), with a further five to seven samples collected at ~3 mm intervals leading from the TM to umbo (Jew et al. 2013) with one repeat sample collected per shell. The number of non-terminal margin samples varied depending on the size of each shell to ensure at least 50% of the shell’s lifespan was sampled. Each sample was collected on a square of aluminium foil that had been wiped with ethanol beforehand, placed into a pre labelled and weighed microfuge tube, then weighed again to ensure the sample met the required ~100 μm. A clean square of aluminium was laid for each sample collected. In between each sample being collected, the rotary tool, cylinder point and surface of the shell was washed, wiped with ethanol and allowed to dry before continuing with the sampling process.

In total, 109 samples were collected. Seventeen samples were taken from the two modern specimens of *Marcia hiantina* MA04 and MA10. Ninety-two samples were taken from the archaeological shell. Fifty-three were from the etched samples EA01–EA07. Of the remaining archaeological shell, 92 samples were collected from seven etched shells, with 39 collected from the non-etched shell, A02–A06.

Isotopic analysis

Carbonate oxygen isotope analyses were conducted using Nu Horizon GasPrep in line with a Nu Instruments Isotope-ratio mass spectrometer. Samples were run using a modified version of the procedure described by Spötl and Vennemann (2002) using a single needle and manually injected acid. Considerable discussion exists about whether oxygen isotope analysis of the carbonate or phosphate portion of biominerals is the most appropriate approach for archaeological applications (Bryant et al. 1996; Chenery et al. 2012). For this research, the carbonate fraction was selected for analysis since sample preparation for this process is more straightforward and thereby less likely to introduce operator error. Carbon isotope values are a by-product of $\delta^{16}O$/ $\delta^{18}O$ analysis, they are presented in the results for completeness but not included in the analysis as seasonal influx of freshwater into the estuaries distorts these values (Andrus 2011:2898; Burchell et al 2014:242–243; Culleton et al. 2009; Milano et al 2016:14–15).

Equation and standards

$\delta^{16}O$/ $\delta^{18}O$ values are determined through being measured against known standards to corrected for drift and peak size using 2-point corrections. The standards used were referenced to the ANU P3 (calcite; $\delta^{18}O = -0.3$ ‰) and UAC-1 (calcium carbonate; $\delta^{18}O = -18.4$ per mil) standards, with IAEA CO-8 (calcite; $\delta^{18}O = -22.7$ per mil) included for quality control using the Epstein et al. (1953) equation:

$$\delta\ (‰) = [(R\text{sample} / R\text{standard} - 1)] \times 1000 \text{ (Equation 2.1}$$

R is the ratio of heavy (18O) to (16O) light isotope. *R*sample is the unknown isotopic ratio of the sample whereas *R*standard is the referenced standard being used to correlate for drift and other error (Epstein et al. 1953; Leng and Lewis 2016:298).

CHAPTER 5 RESULTS

This chapter presents the results from the stable oxygen isotope analysis of modern and archaeological *M. hiantina* shells collected from SM:88. 109 spot samples were collected from 14 shells. The range of these values is presented for individual shells and by group (modern, non-etched and etched), followed by the results of the values from terminal margins of these shells.

XRD Analysis

The XRD results (Appendix 1) returned for the archaeological shells indicated there was no calcite in the samples, meaning recrystallisation has not occurred in the selected shells and they were viable for isotopic analysis.

Isotope analysis

Modern shell

The distribution of $\delta^{18}O$ for both modern shells samples shows two high peaks curving into a central low peak, illustrating that the analysis captured at least one full seasonal cycle. Seventeen samples were collected for isotope analysis from the modern specimens MA04 (n=9) and MA10 (n=8) (Table 6, Figure 11). MA04 ranges from -1.01‰ $\delta^{18}O$ to -5.30‰ $\delta^{18}O$.The overall difference is quite high at 4.29‰ $\delta^{18}O$. The MA10 range was -1.75‰ $\delta^{18}O$ to -3.27‰ $\delta^{18}O$.The overall difference was less, 1.52‰ $\delta^{18}O$ (Table 6, Figure 11).

$\delta^{13}C$ and $\delta^{18}O$ results for MA04 and MA10 (modern shell)

Sample Spot	$\delta^{13}C$	$\delta^{13}C$ σ	$\delta^{18}O$	$\delta^{18}O$ σ
MA04-01	-3.53	0.04	-1.01	0.11
MA04-02	-3.86	0.03	-4.08	0.05
MA04-03	-3.96	0.00	-4.01	0.02
MA04-04	-4.56	0.02	-5.30	0.05
MA04-04r	-4.46	0.03	-5.29	0.05
MA04-05	-4.32	0.05	-4.56	0.05
MA04-06	-3.52	0.04	-3.99	0.03
MA04-07	-3.18	0.01	-3.32	0.06
MA04-TM	-3.50	0.02	-2.74	0.05
MA10-01	-3.14	0.05	-2.30	0.05
MA10-01r	-3.18	0.04	-2.27	0.07
MA10-02	-5.22	0.02	-2.93	0.04
MA10-03	-5.33	0.04	-3.27	0.05
MA10-04	-3.88	0.01	-3.08	0.01
MA10-05	-3.86	0.02	-2.67	0.02
MA10-06	-3.68	0.05	-2.14	0.04
MA10-TM	-2.91	0.03	-1.75	0.06

Table 6 Isotope $\delta^{13}C$ and $\delta^{18}O$ values for modern *M. hiantina* (VPDB)

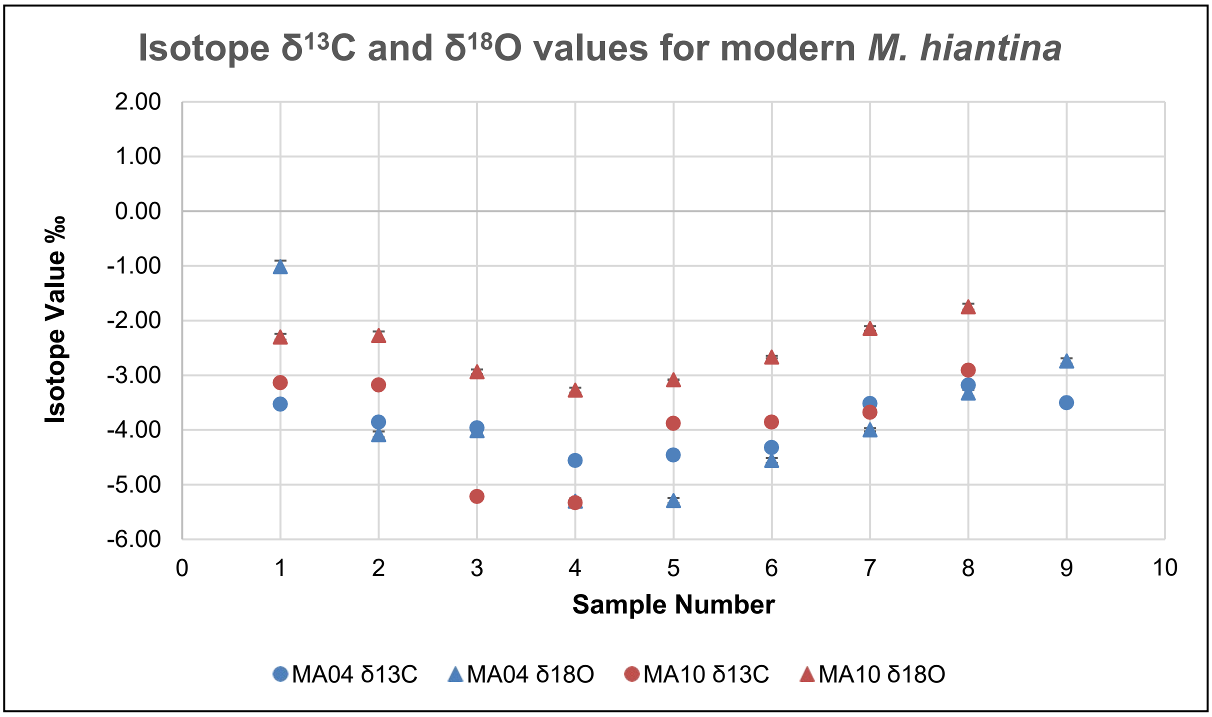

Figure 11 Isotope $\delta^{13}C$ and $\delta^{18}O$ values for modern *M. hiantina* (VPDB)

Archaeological shell

Five shell samples were not etched in HCL. Samples A02–A06 correspond with the excavated units XU02–XU06, A02 with XU02, and A03 with XU03 to XU06. The $\delta^{18}O$ values of these samples illustrate the environmental and climatic fluctuations through their life cycles. The value recorded for the terminal margin provides an estimate for season of death, and therefore harvesting. Extrapolating these values for the all the shells provides an estimate the seasonality for that unit. The range of values for A02–A06 varied quite widely from 1.23‰ δ^{18}O to -1.85‰ δ^{18}O (Figure 12).

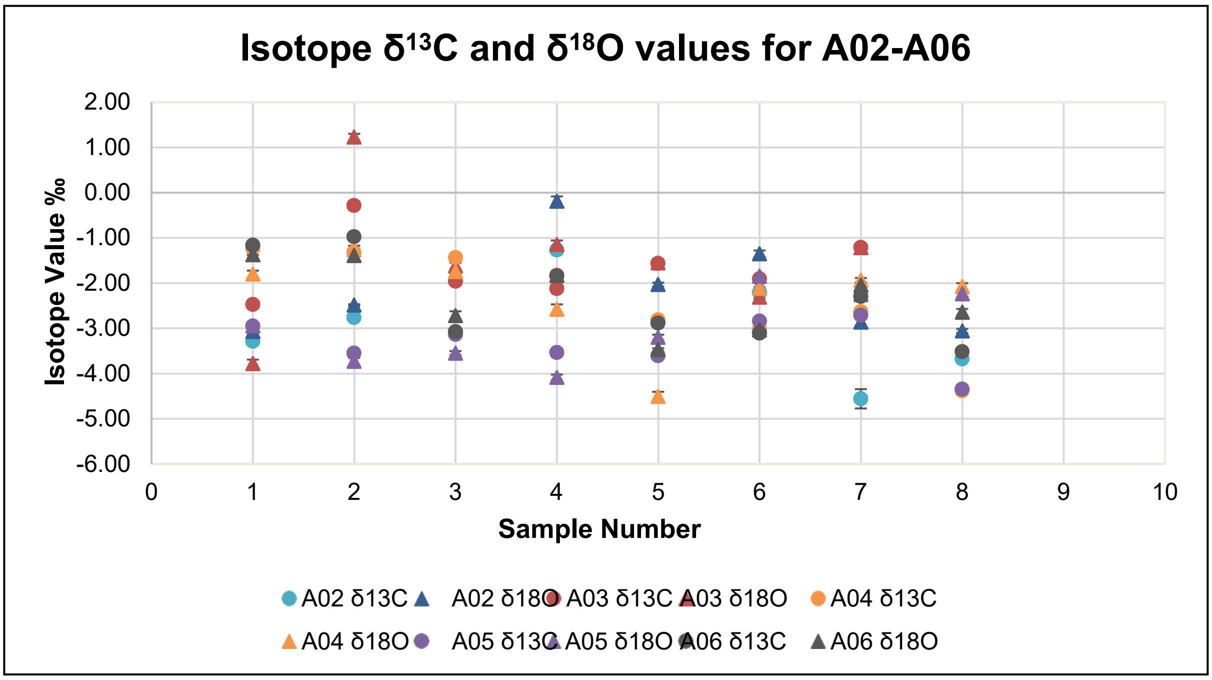

Figure 12 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, A02–A06 (VPDB)

A02

A02 was collected from XU02, the pattern indicates one central high peak with two low points either side, again illustrating the capture of at least one full seasonal cycle. (Table 7, Figure 13). A02 values (n=8) range from -0.19‰ δ^{18}O to -3.07‰ δ^{18}O, the difference is 2.88‰ δ^{18}O.

δ^{13}C and δ^{18}O results for A02 (SM:88 XU02)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
A02-01	-3.29	0.00	-3.07	0.04
A02-02	-2.77	0.01	-2.48	0.02
A02-03	Null value	Null value	Null value	Null value
A02-04	-1.27	0.08	-0.19	0.11
A02-05	-2.86	0.03	-2.03	0.04
A02-05r	-2.21	0.04	-1.35	0.07
A02-06	-4.56	0.21	-2.86	0.08
A02-TM	-3.68	0.03	-3.06	0.05

Table 7 Isotope δ^{13}C and δ^{18}O values for archaeological shell (non-etched) *M. hiantina*, A02 (VPDB)

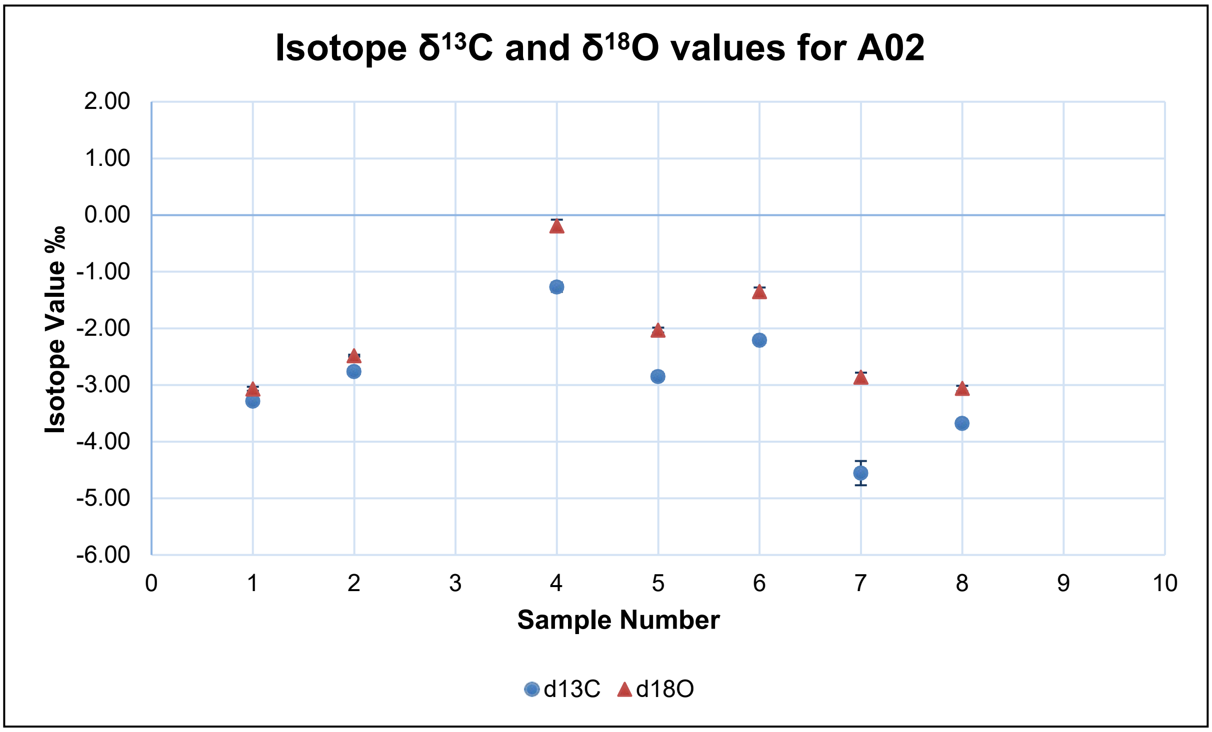

Figure 13 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, A02 (VPDB)

A03

A03 was collected from XU03 and recorded the greatest variation of all the archaeological shell (Table 8, Figure 14). It has a distinctive positive peak that records the greatest maximum value. This peak is followed by almost constant values up to and including the terminal margin (-1.22‰ δ^{18}O), indicative of a stable, dry environment. The isotopic values for A03 (n=7) display a range from 1.23‰ δ^{18}O to -3.78‰ δ^{18}O, the difference is 5.01‰ δ^{18}O.

δ^{13}C and δ^{18}O results for A03 (SM:88 XU03)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
A03-01	-2.48	0.03	-3.78	0.09
A03-02	-0.29	0.01	1.23	0.07
A03-03	-1.96	0.03	-1.62	0.07
A03-03r	-2.13	0.03	-1.15	0.09
A03-04	-1.56	0.02	-1.56	0.08
A03-05	-1.91	0.03	-2.31	0.03
A03-TM	-1.21	0.03	-1.22	0.04

Table 8 Isotope δ^{13}C and δ^{18}O values for archaeological shell (non-etched) *M. hiantina*, A03 (VPDB)

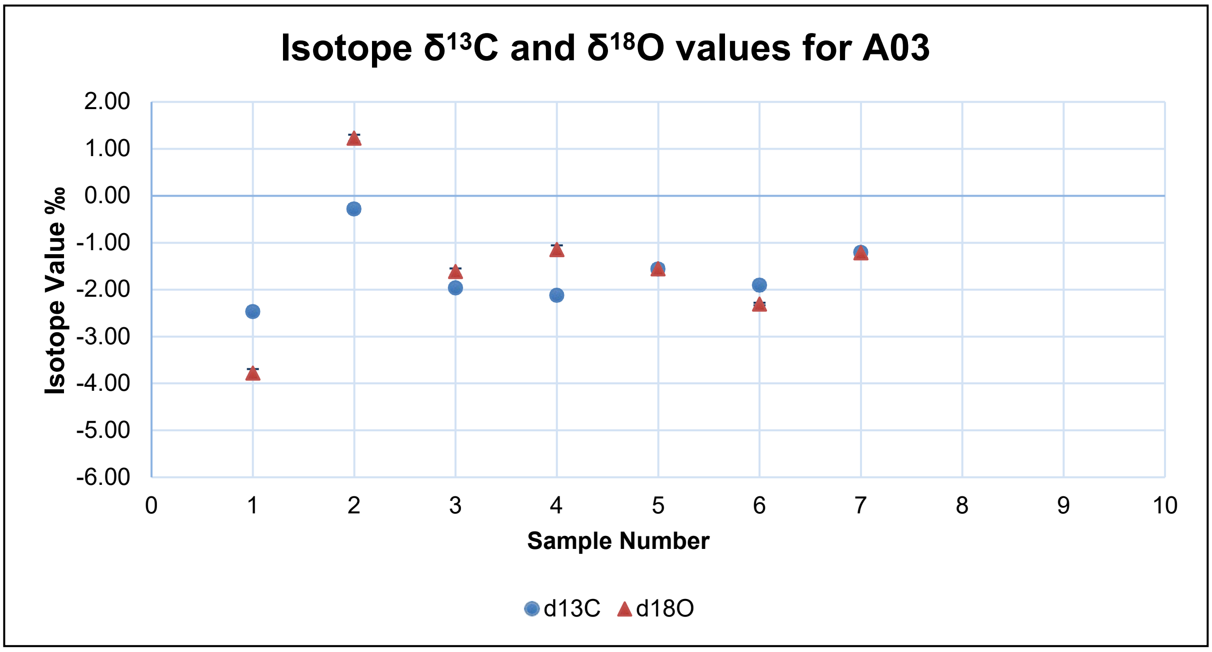

Figure 14 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, A03 (VPDB)

A04

A04 was collected from XU04, it has two high peaks with a central low point, indicative of capturing a full seasonal cycle (Table 9, Figure 15). The isotopic values for A04 (n=8) range from -1.26‰ δ^{18}O to -4.50‰ δ^{18}O, the difference is 3.24‰ δ^{18}O. The terminal margin value was one of the more positive values recorded in the span of this shell (- 2.08‰ δ^{18}O, Table 9).

δ^{13}C and δ^{18}O results for A04 (SM:88 XU04)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
A04-01	-1.24	0.15	-1.80	0.08
A04-01r	-1.32	0.06	-1.26	0.09
A04-02	-1.44	0.04	-1.75	0.05
A04-03	-1.83	0.04	-2.58	0.11
A04-04	-2.82	0.06	-4.50	0.10
A04-05	-3.02	0.03	-2.12	0.03
A04-06	-2.63	0.02	-1.94	0.05
A04-TM	-4.38	0.05	-2.08	0.07

Table 9 Isotope δ^{13}C and δ^{18}O values for archaeological shell (non-etched) *M. hiantina*, A04 (VPDB)

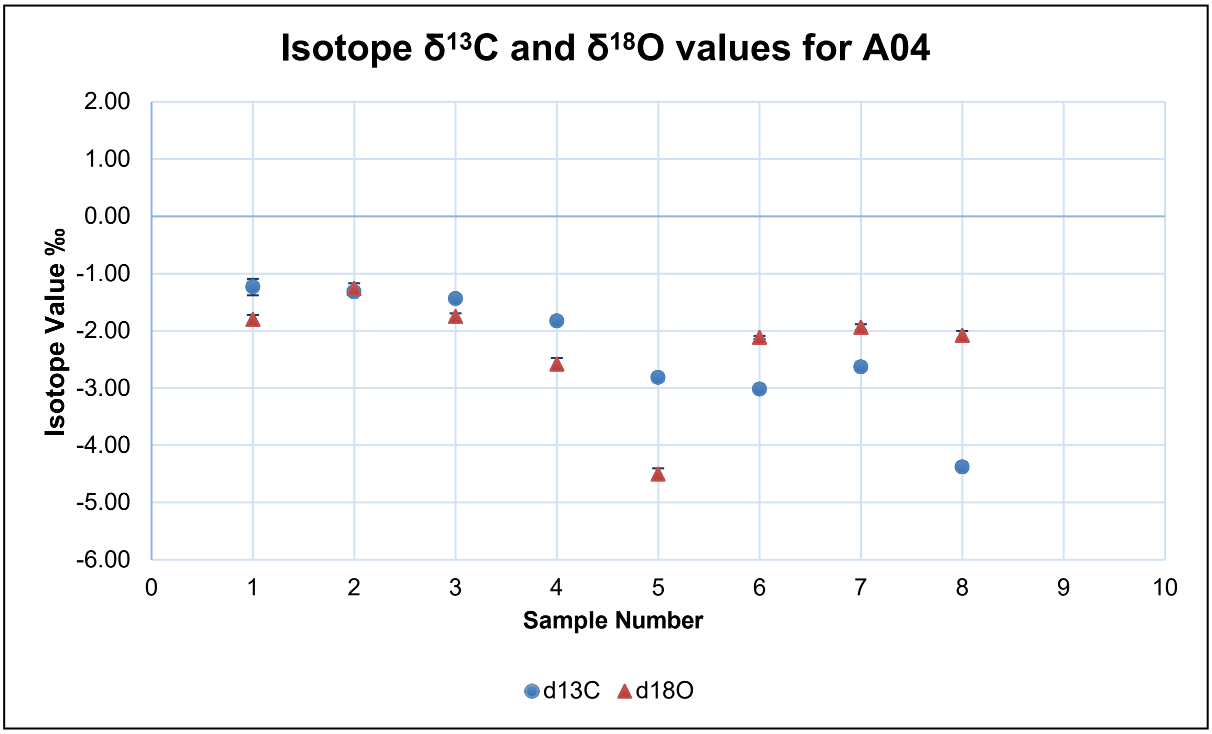

Figure 15 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, A04 (VPDB)

A05

A05 was collected from XU05 and shows minor variability between spot sample 1–5 before trending into more positive values with proximity to the terminal margin (Table 10, Figure 16). The isotope values for A05 (n=8) range from -1.85‰ δ^{18}O to -4.09‰ δ^{18}O, the difference is 2.24‰ δ^{18}O. The terminal margin value (-2.24‰ δ^{18}O) is within the more positive range of values recorded for A05 (Table 10, Figure 16).

δ^{13}C and δ^{18}O results for A05 (SM:88 XU05)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
A05-01	-2.95	0.05	-2.94	0.02
A05-02	-3.55	0.04	-3.73	0.08
A05-03	-3.14	0.00	-3.55	0.04
A05-03r	-3.54	0.05	-4.09	0.06
A05-04	-3.61	0.05	-3.20	0.06
A05-05	-2.84	0.02	-1.85	0.03
A05-06	-2.71	0.01	-2.25	0.08
A05-TM	-4.35	0.04	-2.24	0.06

Table 10 Isotope δ^{13}C and δ^{18}O values for archaeological shell (non-etched) *M. hiantina*, A05 (VPDB)

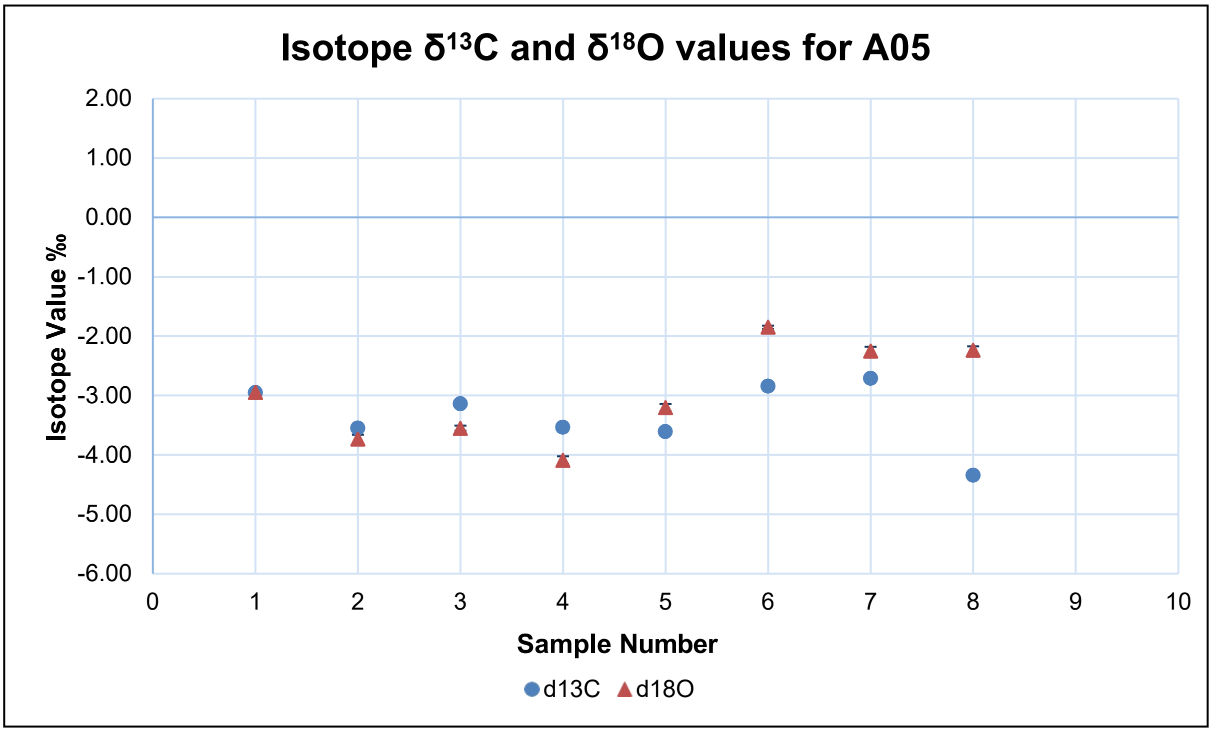

Figure 16 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, A05 (VPDB)

A06

A06 was collected from XU06 and depicts a trend punctuated with multiple peaks and lows, though the difference across all samples represents reduced environmental variability (Table 11, Figure 17). The isotope values for A06 (n=8) range from -1.38‰ δ^{18}O to -3.47‰ δ^{18}O, with a difference of 2.09‰ δ^{18}O. The terminal margin value (-2.64‰ δ^{18}O) is close to the mean value for the recorded lifespan of the shell.

δ^{13}C and δ^{18}O results for A06 (SM:88 XU06)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
A06-01	-1.16	0.08	-1.38	0.08
A06-02	-0.98	0.02	-1.39	0.01
A06-03	-3.08	0.05	-2.72	0.10
A06-03r	-1.84	0.04	-1.83	0.05
A06-04	-2.89	0.05	-3.47	0.03
A06-05	-3.11	0.03	-3.04	0.04
A06-06	-2.30	0.03	-2.05	0.05
A06-TM	-3.52	0.04	-2.64	0.07

Table 11 Isotope δ^{13}C and δ^{18}O values for archaeological shell (non-etched) *M. hiantina*, A06 (VPDB)

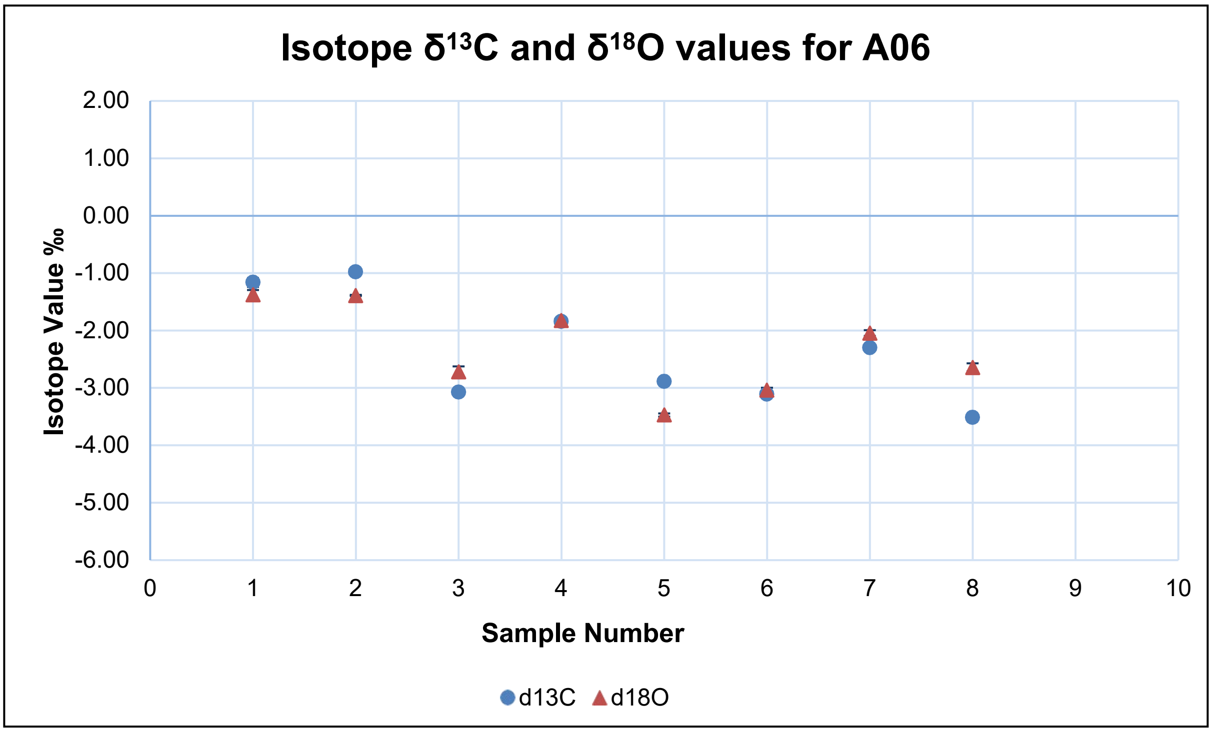

Figure 17 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, A06 (VPDB)

Etched archaeological shell

Samples EA01–EA07 are the seven shell specimens that were etched with HCL to test the premise this step improves the purity and accuracy of the values (Jew et al. 2013) in comparison with A02–A06. EA01–EA07 correlate with shell collected from units XU01–XU07, EA01 with XU01, and EA02 with XU02. Samples EA01–EA07 range from 0.46‰ δ^{18}O to -4.5‰ δ^{18}O (Figure 18).

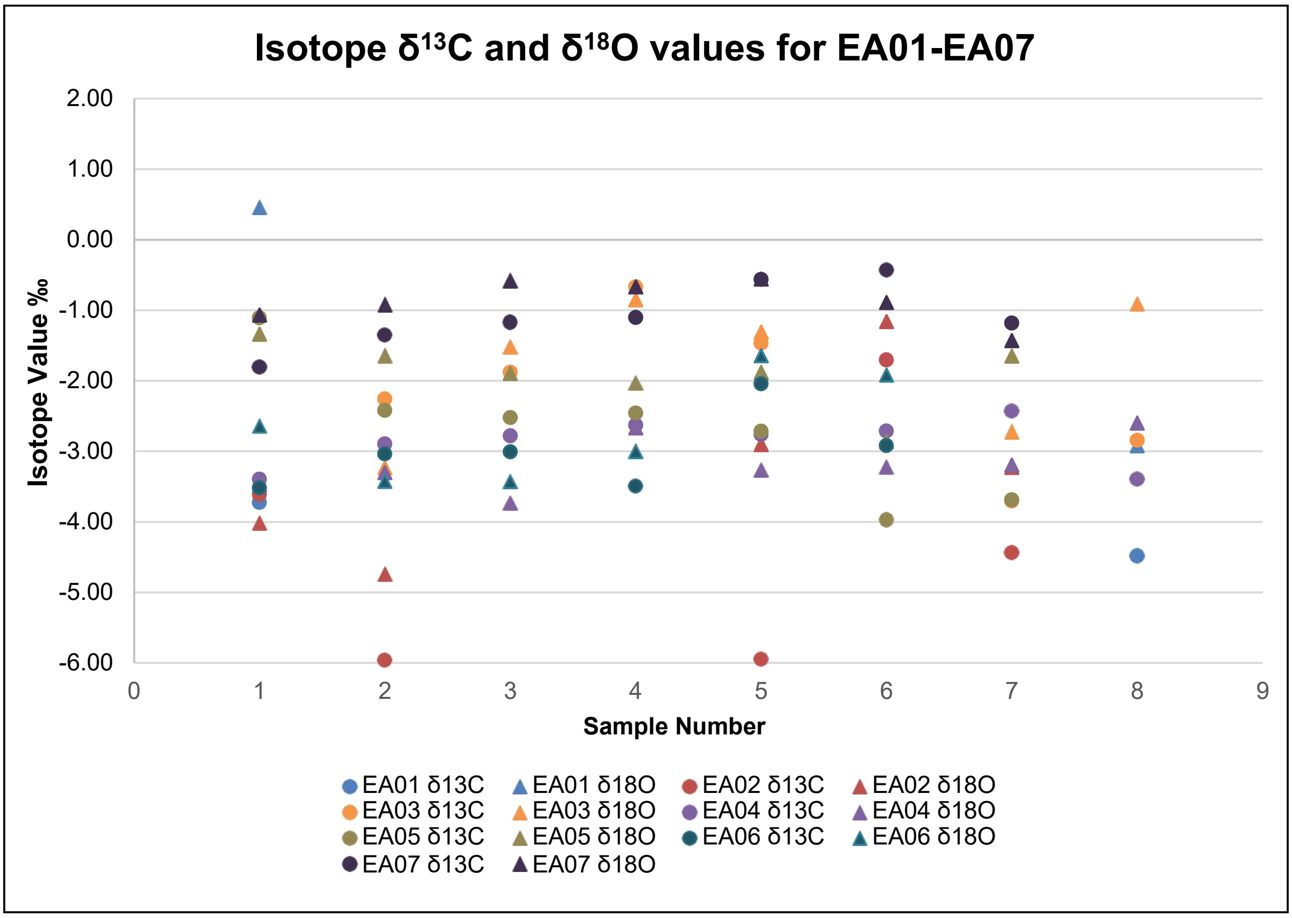

Figure 18 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA01–EA07 (VPDB)

EA01

EA01 corresponds with XU01, with early growth increments showing a pronounced peak followed by steep descent that eases into a low point before trending upwards to the more positive values again (Table 12, Figure 19). The isotopic values (n=8) (Table 12, Figure 19) range between -0.46‰ δ^{18}O and -4.01‰ δ^{18}O, with a difference of 4.47‰ δ^{18}O. The value of the terminal margin (-2.92‰ δ^{18}O) is one of the more negative values for this shell (Table 12).

δ^{13}C and δ^{18}O results for EA01 (SM:88 XU01)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
EA01-01	-3.73	0.08	0.46	0.04
EA01-01r	-3.61	0.04	-2.29	0.05
EA01-02	-4.87	0.02	-3.04	0.05
EA01-03	-4.00	0.02	-3.35	0.07
EA01-04	-4.21	0.05	-4.01	0.08
EA01-05	-2.54	0.04	-3.99	0.06
EA01-06	-2.64	0.02	-3.12	0.07
EA01-TM	-4.48	0.03	-2.92	0.06

Table 12 Isotope δ^{13}C and δ^{18}O values for archaeological shell (etched) *M. hiantina*, EA01 (VPDB)

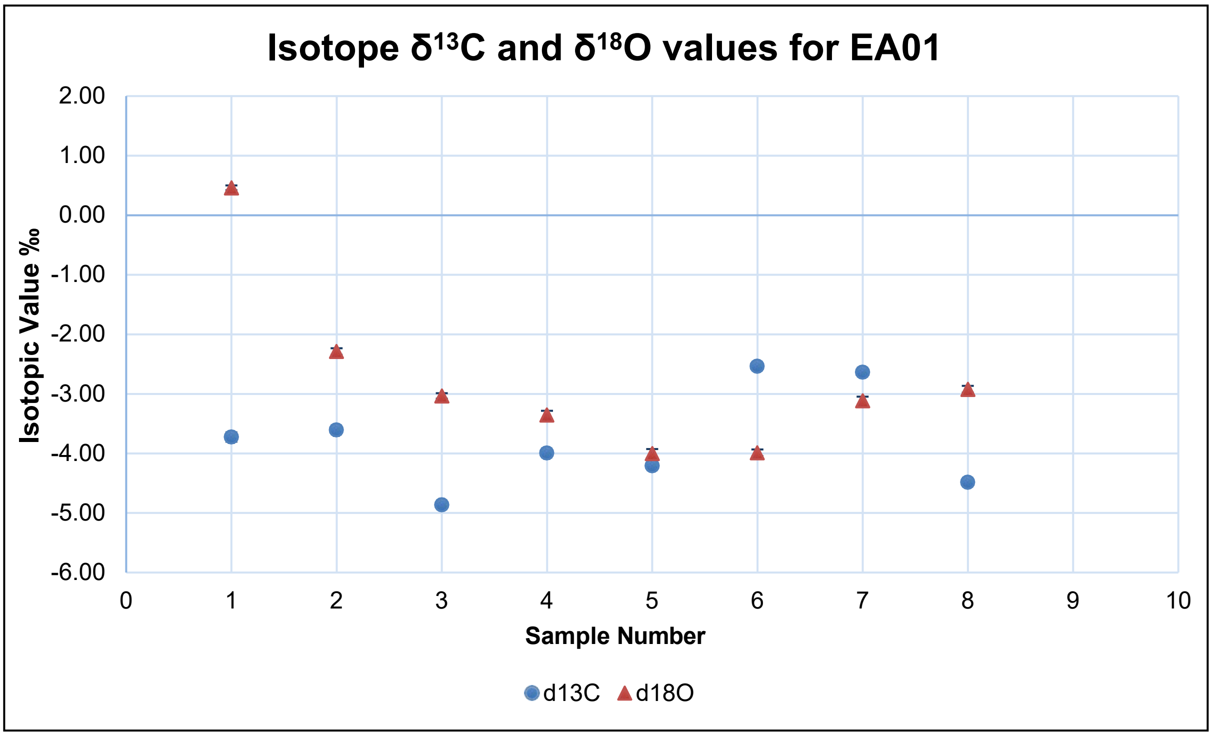

Figure 19 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA01 (VPDB).

EA02

EA02 corresponds with XU02, and shows a strong central peak at sample spot #6 with preceding low point and followed by a waning into negative values (Table 13, Figure 20). This pattern indicates a full seasonal cycle was captured in the sampling process for EA02. The isotopic values for EA02 (n=8) range from -1.16‰ δ^{18}O, to -4.74‰ δ^{18}O, the difference is 3.58‰ δ^{18}O. The terminal margin value (-3.50‰ δ^{18}O) is among the more negative values indicated for this shell.

δ^{13}C and δ^{18}O results for EA02 (SM:88 XU02)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
EA02-01	-3.61	0.05	-4.02	0.08
EA02-02	-5.96	0.05	-4.74	0.02
EA02-03	-2.68	0.03	-3.07	0.05
EA02-04	-2.60	0.04	-1.93	0.06
EA02-04r	-5.95	0.05	-2.90	0.03
EA02-05	-1.70	0.04	-1.16	0.02
EA02-06	-4.44	0.03	-3.23	0.08
EA02-TM	-3.45	0.01	-3.50	0.05

Table 13 Isotope δ^{13}C and δ^{18}O values for archaeological shell (etched) *M. hiantina*, EA02 (VPDB)

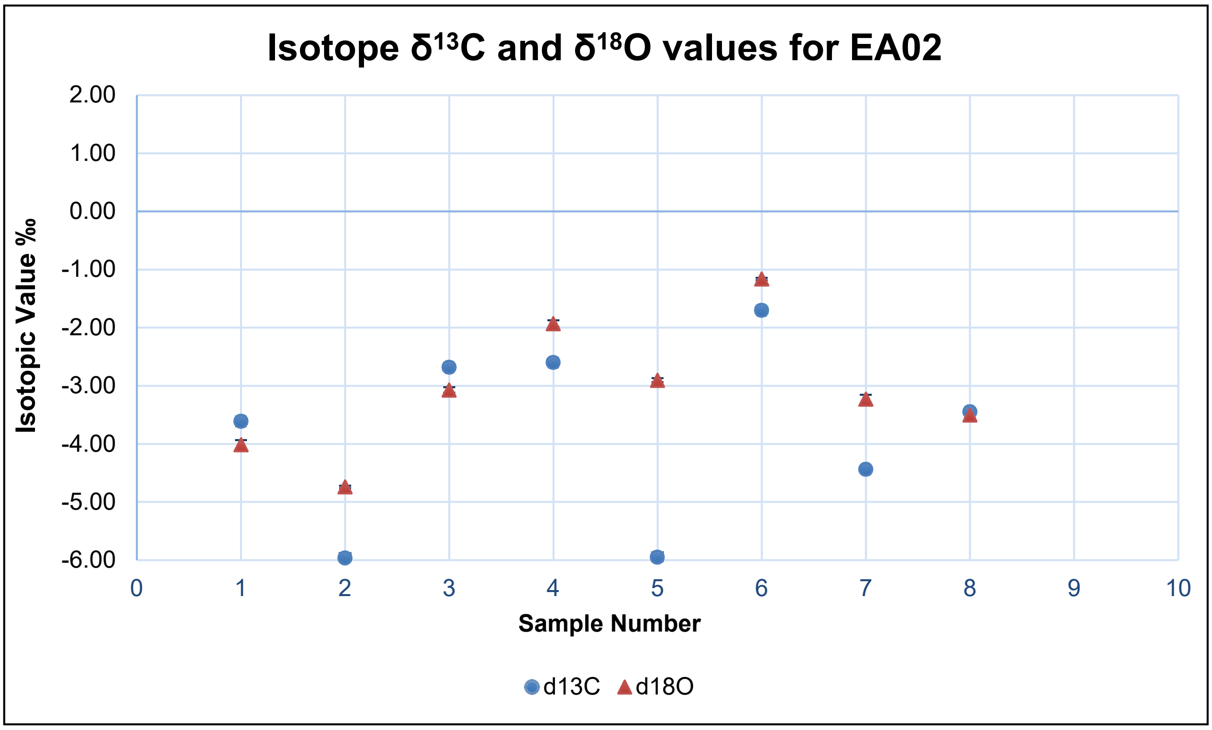

Figure 20 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA02 (VPDB).

EA03

EA03 corresponds with XU03, the trend begins with the most negative value followed by two peaks at sample spot 4 and the terminal margin (Table 14, Figure 21). The EA03 values (n=8) range from -0.85‰ δ^{18}O to -5.17‰ δ^{18}O, with a difference of 4.32‰ δ^{18}O. The terminal margin (-0.91‰ δ^{18}O) is the second highest value (by 0.06‰) for this sample (Table 14, Figure 21).

δ^{13}C and δ^{18}O results for EA03 (SM:88 XU03)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
EA03-01	-3.10	0.05	-5.17	0.06
EA03-02	-2.26	0.03	-3.23	0.10
EA03-03	-1.88	0.06	-1.52	0.10
EA03-04	-0.67	0.02	-0.85	0.01
EA03-05	-1.47	0.02	-1.31	0.04
EA03-05r	-0.97	0.06	-1.61	0.07
EA03-06	-3.71	0.02	-2.72	0.06
EA03-TM	-2.85	0.01	-0.91	0.02

Table 14 Isotope δ^{13}C and δ^{18}O values for archaeological shell (etched) *M. hiantina*, EA03 (VPDB)

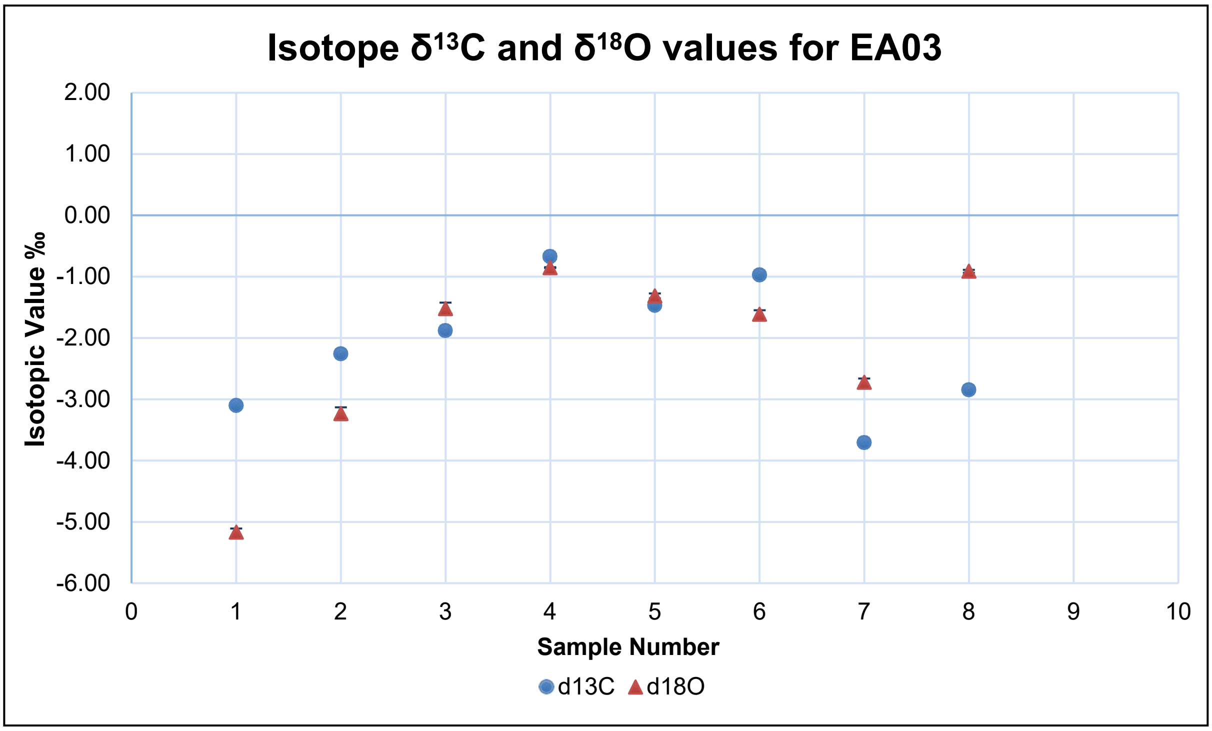

Figure 21 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA03 (VPDB).

EA04

EA01 was collected from XU04. The trend for this shell is quite level, with a subtle peak at spot sample 4 and the terminal margin (Table 15, Figure 22). The isotopic values (n=8) range from -2.60‰ δ^{18}O to -3.73‰ δ^{18}O, the difference is 1.13‰ δ^{18}O. The terminal margin (-2.60‰ δ^{18}O) was the highest value recorded for this shell (Table 15).

δ^{13}C and δ^{18}O results for EA04 (SM:88 XU04)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
EA04-01	-3.40	0.03	-3.48	0.05
EA04-02	-2.90	0.02	-3.30	0.06
EA04-03	-2.78	0.02	-3.73	0.08
EA04-04	-2.63	0.05	-2.67	0.09
EA04-05	-2.76	0.03	-3.27	0.03
EA04-05r	-2.71	0.03	-3.22	0.06
EA04-06	-2.43	0.03	-3.20	0.05
EA04-TM	-3.40	0.03	-2.60	0.03

Table 15 Isotope δ^{13}C and δ^{18}O values for archaeological shell (etched) *M. hiantina*, EA04 (VPDB)

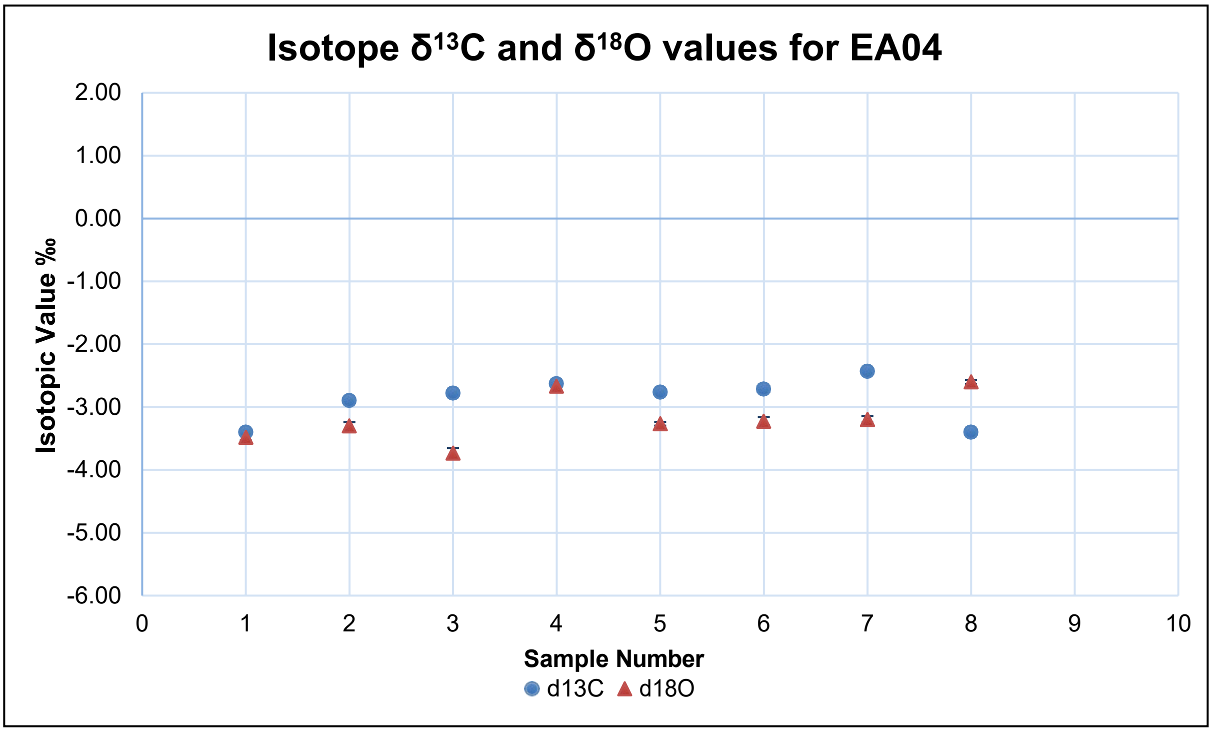

Figure 22 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA04 (VPDB)

EA05

EA05 corresponds with XU05. The values show a trend that starts with a peak, then gradually declines before hitting a marked low point at sample spot 6, followed immediately by a second peak at the terminal margin (Table 16, Figure 23). The isotopic values (n=7) range from -1.34‰ δ^{18}O to -2.86‰ δ^{18}O, with a difference of 1.52‰ δ^{18}O. The terminal margin (-1.65) is the second highest value by 0.01‰ (Table 16).

δ^{13}C and δ^{18}O results for EA05 (SM:88 XU05)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
EA05-01	-1.11	0.05	-1.34	0.12
EA05-02	-2.42	0.03	-1.64	0.01
EA05-03	-2.52	0.03	-1.90	0.03
EA05-04	-2.46	0.03	-2.04	0.04
EA05-04r	-2.72	0.03	-1.88	0.12
EA05-05	-3.97	0.03	-2.86	0.04
EA05-TM	-3.69	0.04	-1.65	0.07

Table 16 Isotope δ^{13}C and δ^{18}O values for archaeological shell (etched) *M. hiantina*, EA05 (VPDB)

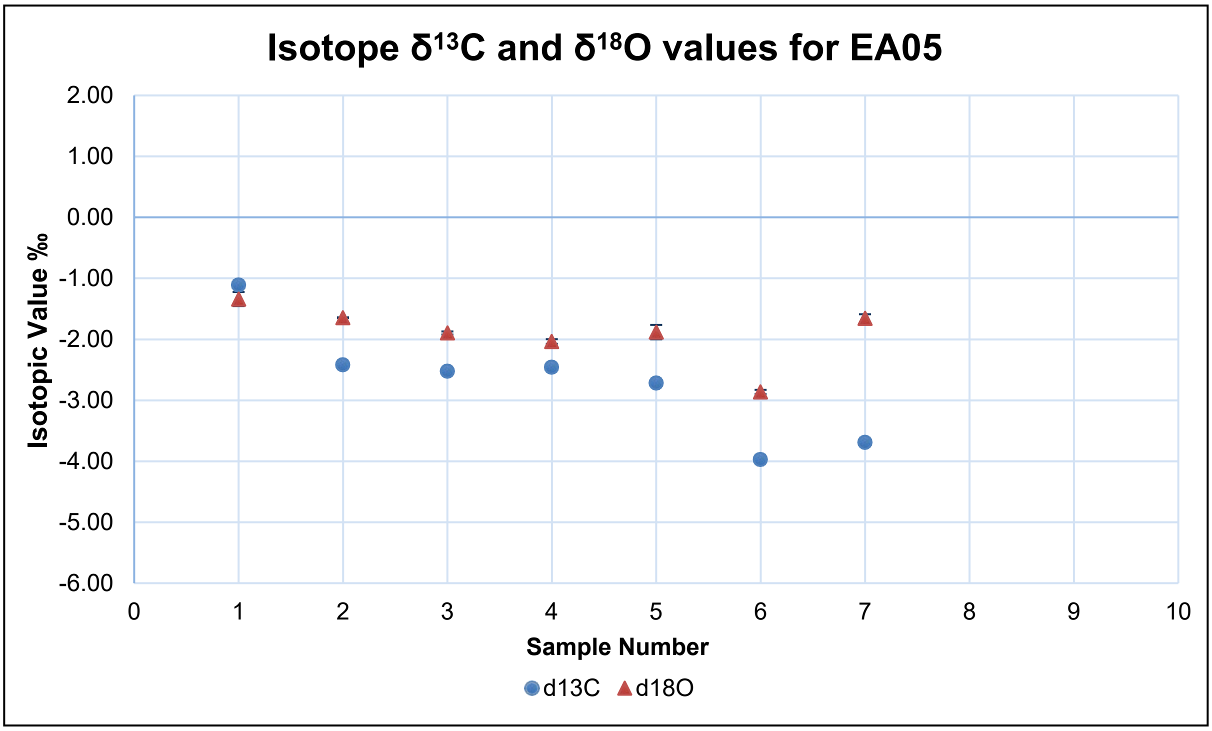

Figure 23 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA05 (VPDB).

EA06

EA06 was collected from XU06. The trend for this shell is relatively level from sample spot 1–4, before reaching a subtle peak at sample spot 5 (Table 17, Figure 24). The isotopic values for EA06 (n=7) range from -1.64‰ δ^{18}O to -3.43‰, with a difference of 1.79‰ δ^{18}O. The terminal margin (-2.29‰ δ^{18}O) is one of the higher values (Table 17).

δ^{13}C and δ^{18}O results for EA06 (SM:88 XU06)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
EA06-01	-3.52	0.02	-2.64	0.05
EA06-02	-3.04	0.02	-3.43	0.05
EA06-02r	-3.01	0.03	-3.43	0.08
EA06-03	-3.50	0.04	-3.00	0.10
EA06-04	-2.04	0.03	-1.64	0.05
EA06-05	-2.92	0.04	-1.92	0.08
EA06-TM	-3.62	0.03	-2.29	0.04

Table 17 Isotope δ13C and δ18O values for archaeological shell (etched) *M. hiantina*, EA06 (VPDB)

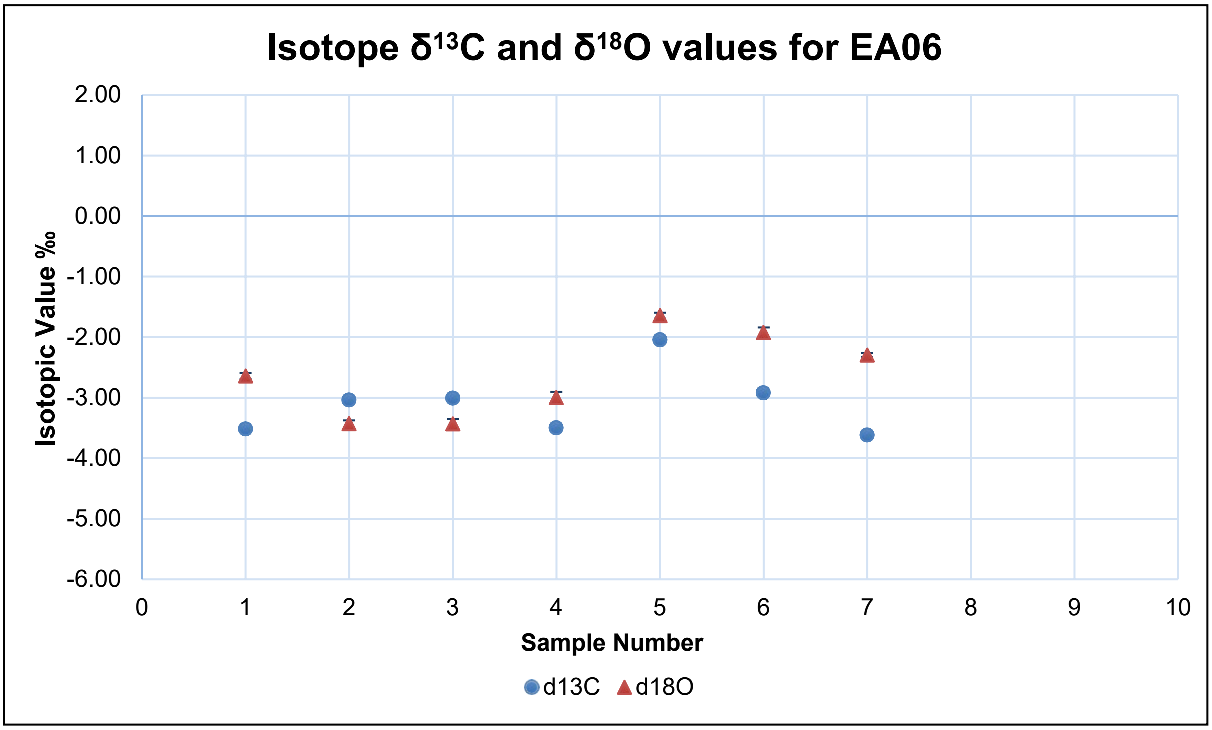

Figure 24 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA06 (VPDB).

EA07

EA07 was the sole shell selected from XU07. The trend is one of very little variability (Table 18, Figure 25). The isotopic values for EA07 range from -0.56‰ δ^{18}O to -1.43‰ δ^{18}O, the overall difference is 0.87‰ δ^{18}O. The terminal margin (-1.43‰ δ^{18}O) is lowest value recorded (Table 18).

δ^{13}C and δ^{18}O results for EA07 (SM:88 XU07)

Sample Spot	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
EA07-01	-1.81	0.04	-1.07	0.09
EA07-02	-1.35	0.06	-0.92	0.08
EA07-03	-1.17	0.04	-0.58	0.12
EA07-03r	-1.10	0.02	-0.67	0.05
EA07-04	-0.56	0.05	-0.56	0.04
EA07-05	-0.43	0.06	-0.89	0.08
EA07-TM	-1.18	0.06	-1.43	0.08

Table 18 Isotope δ^{13}C and δ^{18}O values for archaeological shell (etched) *M. hiantina*, EA07 (VPDB)

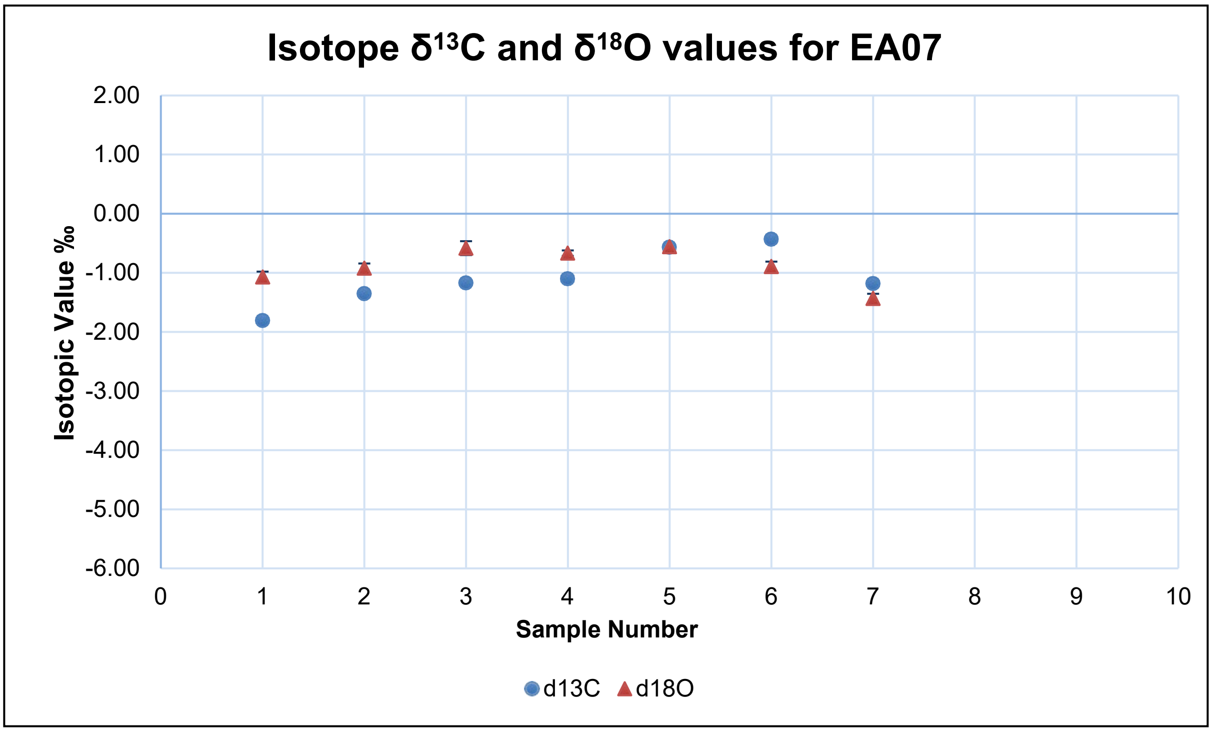

Figure 25 Isotope δ^{13}C and δ^{18}O values for *M. hiantina*, EA07 (VPDB)

Terminal margins

The terminal margins across all the modern and archaeological shells (n=14) are presented in Table 19 and Figure 26. MA04 marks the end of the wet, post-wet, season in Weipa and MA10 marks the late dry season, providing a framework for understanding the archaeological values. Very few values are recorded outside of MA04 and MA10. The range for all the terminal margins is from -0.91‰ δ^{18}O to min -4.48‰ δ^{18}O, with a difference of 3.57‰ δ^{18}O.

Sample	δ^{13}C	δ^{13}C σ	δ^{18}O	δ^{18}O σ
MA04	-3.50	0.02	-2.74	0.05
MA10	-2.91	0.03	-1.75	0.06
A02	-3.68	0.03	-3.06	0.05
A03	-1.21	0.03	-1.22	0.04
A04	-4.38	0.05	-2.08	0.07
A05	-4.35	0.04	-2.24	0.06
A06	-3.52	0.04	-2.64	0.07
EA01	-4.48	0.03	-4.48	0.03
EA02	-3.45	0.01	-3.50	0.05
EA03	-2.85	0.01	-0.91	0.02
EA04	-3.40	0.03	-2.60	0.03
EA05	-3.69	0.04	-1.65	0.07
EA06	-3.62	0.03	-2.29	0.04
EA07	-1.18	0.06	-1.43	0.08

Table 19 Terminal margin isotope δ^{13}C and δ^{18}O values for all shell M. hiantina (VPDB)

$\delta^{13}C$ and $\delta^{18}O$ results for all terminal margin (SM:88 XU07)

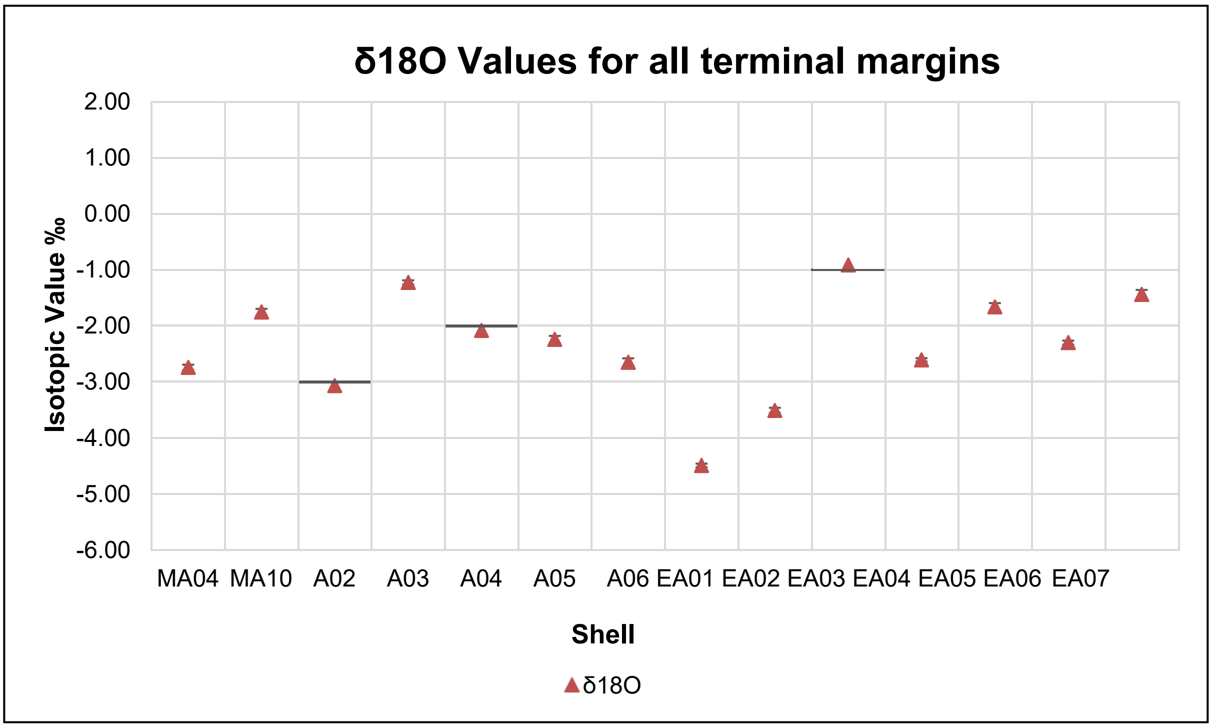

Figure 26 Isotope $\delta^{18}O$ values for the terminal margins of all *M. hiantina* shell (VPDB)

Standards

A total of 109 samples was analysed for $\delta^{13}C$ and $\delta^{18}O$ values across three runs. There are two standard deviations that need to be taken into consideration. These are the weighted mean standard deviation (σ) of the standard sample which will be the same for all samples processed in a single run. The internal precision of each measurement will vary between individual samples and is presented as the standard deviation of the three sample peaks. The weighted mean σ of the three runs were in the order 0.05–0.08 for $\delta^{13}C$ and 0.10–0.13 for $\delta^{18}O$ (Table 20). The $\delta^{13}C$ values are included for completeness but not included in the analysis. For one sample, A02-03, the gas escaped the tube during analysis returning a null value. The maximum, minimum, and range values for each shell are charted in Table 21.

Spot #	MA 04	MA 10	A 02	A 03	A 04	A 05	A 06	EA 01	EA 02	EA 03	EA 04	EA 05	EA 06	EA 07
1	🟩 01	🟧 01	🟩 01	🟦 01	🟦 01	🟩 01	🟧 01	🟩 01	🟦 01	🟧 01	🟩 01	🟩 01	🟩 01	🟩 01
2	🟩 02	🟧 01r	🟩 02	🟩 02	🟦 01r	🟧 02	🟦 02	🟧 01r	🟩 02	🟩 02	🟩 02	🟩 02	🟩 02	🟩 02
3	🟩 03	🟧 02	03	🟦 03	🟧 02	🟦 03	🟦 03	🟧 02	🟧 03	🟩 03	🟩 03	🟩 03	🟩 02r	🟩 03
4	🟦 04	🟧 3	🟩 04	🟦 03r	🟦 03	🟦 03r	🟦 03r	🟧 03	🟧 04	🟩 04	🟩 04	🟩 04	🟩 03	🟩 03r
5	🟧 04r	🟩 04	🟦 05	🟦 04	🟩 04	🟦 04	🟦 04	🟧 04	🟩 04r	🟦 05	🟦 05	🟩 04r	🟦 04	🟩 04
6	🟦 05	🟩 05	🟦 05r	🟧 05	🟦 05	🟧 05	🟧 05	🟧 05	🟦 05	🟧 05r	🟦 05r	🟩 05	🟩 05	🟩 05
7	🟩 06	🟩 06	🟩 06	🟩 TM	🟧 06	🟧 06	🟧 06	🟧 06	🟦 06	🟩 06	🟩 06	🟩 TM	🟧 TM	🟦 TM
8	🟩 07	🟩 TM	🟩 TM		🟧 TM	🟧 TM	🟧 TM	🟩 TM	🟧 TM	🟩 TM	🟩 TM			
9	🟩 TM													

Weighted mean σ

Run	δ13C	δ18O
🟩 **1**	0.06	0.11
🟦 **2**	0.08	0.13
🟧 **3**	0.05	0.10

Table 20 Weighted mean σ of standard sample across all runs

	MA04	MA10	A 02	A 03	A 04	A 05	A 06	EA 01	EA 02	EA 03	EA 04	EA 05	EA 06	EA 07
Max	-1.01	-1.75	-0.19	1.23	-1.26	-1.85	-1.38	0.46	-1.16	-0.85	-2.6	-1.34	-1.64	-0.56
Min	-5.3	-3.27	-3.07	-3.78	-4.5	-4.09	-3.47	-4.01	-4.74	-5.17	-3.73	-2.86	-3.43	-1.43
Range	4.29	1.52	2.88	5.01	3.24	2.24	2.09	4.47	3.58	4.32	1.13	1.52	1.79	0.87

Table 21 Range of values for all shell ‰ (VPDB)

Summary

The multiple peaks visible in the figures for both modern shell and archaeological shells are a positive indicator that sequential seasonal fluxes have been captured in each sample with the exception of EA07. This supports the premise that these shells are viable for isotopic analysis and have not been negatively affected by the presence of calcite through recrystallisation. These data also show that historical collection events, when investigated isotopically, can accurately reflect the season of death for individual shellfish as is verified by the accurate reflection of the season of death for the two modern specimens. It would appear from first-off interpretation of the results that there is some variation in the seasons of shellfish harvested within SM:88, particularly visible in the data from the etched range of archaeological shell.

CHAPTER 6 DISCUSSION AND CONCLUSION

The primary goal of this thesis was to evaluate the seasonality of shellfish collection practices associated with the formation of shell mounds near Weipa using oxygen isotope analysis. This chapter discusses the results of the analysis in relation to the questions and aims of the study. The reliability of the method is considered before interpreting the site in relation to the $\delta^{18}O$ data and the stratigraphy of SM:88, providing a framework to address the wider question of seasonality of northern Australian shell mounds and the implications for current archaeological models.

Methodological considerations for $\delta^{18}O$ analysis

The use of $\delta^{18}O$ analysis for estimating seasonality is not a new technique (e.g. Shackleton 1973; Leng and Lewis 2016), though sampling methods can vary widely (e.g. Burchell et al. 2013; Jew et al. 2013). The methods employed for this research involved sampling the individual growth increments on the outer surface of the shell. Taking more samples across the lifespan of a shell provides higher resolution data (Andrus 2011:2896), as it provides a more detailed account of seasonal fluctuations during the lifespan of the shellfish. Some researchers sample the entire lifespan of a shell. However, as this analysis is costly some studies have included sampling strategies to test the number of samples required to provide reliable results for seasonality. Jew et al. (2013) sampled shell for accuracy using two strategies. The first involved a sample of the terminal margin with a second sample towards the umbo. The other strategy took six, plus a terminal margin sample. The results agreed with a previous study by Thompson and Andrus (2011:329) which indicated as species grow at varying rates, sampling of the terminal margin and a full season of growth was required for accurate interpretation of individual shell. The strategy adopted here provides a coarse, but very effective, estimate of seasonality, and enabled sampling across at least one full seasonal cycle in a shell's lifespan. In this study the only shells that lacked a sufficiently broad range of values to indicate a full season cycle were EA05 and EA07.

This research did not sample seawater contemporaneous to the modern shell samples to provide the $\delta^{18}O$ values of the surrounding water. As the focus was on determining seasonality rather than allowing direct comparisons with other $\delta^{18}O$ records, no conversions from carbonate to seawater $\delta^{18}O$ values or attempt to use $\delta^{18}O$ as a proxy for seawater temperature was undertaken. Accurate calculations of these values in the absence of local $\delta^{18}O$ values for seawater would be problematic as the estuary adjacent to SM:88 is subject to intensive fluctuations in salinity due to wet season fluctuation. As such the interpretations of seasonality are made solely on the δ^{18}O values. To improve results for future analysis, samples of modern specimens of the targeted shell should be collected with corresponding water samples for each month of a calendar year. This would provide a more detailed and precise baseline for interpreting the results for archaeological shell as well as increasing our understanding of the impact of variable hydrology on shell at a local level.

A further consideration regards the species *M. hiantina* and the homogenous nature of the terminal margin. It has been assumed for this research that the growth increments deposited in the hard shell retain uniform δ^{18}O values to the terminal margin and are not precipitated at irregular intervals. While there is no reason to think this is not the case with samples analysed here, it is a question that should be considered in further research as there are few studies available on the biology of *M. hiantina.*

Insights from modern shell

MA04 was collected in the month of April and recorded a terminal value of -2.74‰ δ^{18}O. The terminal margin value for MA10, collected in mid-October, was -1.75 ‰ δ^{18}O. April is considered post-wet and October is within the dry season. April, being closer to wet season, is considered a warmer, wetter period, but is not within the wet season cycle. These modern values provide an important baseline against which we can interpret the values from archaeological shell, and demonstrate that values with a more negative result than those on MA04 are more closely linked with wet season conditions.

Sea surface temperature (SST) and precipitation, and their effect on salinity, are the main elements that affect δ^{18}O. There is little variation in air temperature annually, though October and November record marginally higher maximums than the rest of the year (Figure 4). When averaged, SST varies by 6°C on average across the year: June–August (26.32°C, 25.42°C, 25.40°C respectively) record the coolest SST temperatures, November–March record the warmest (29.27°C, 31.19°C, 29.77°C, 30.47°C, 30.06°C respectively) (Figure 8). Rainfall events, however, are very pronounced throughout the warmer, wet season and almost absent during the cooler, dry season. June–September (23.6 mm, 9.2 mm, 59.2 mm, 16.6 mm respectively) record almost no rainfall, April/May (328 mm, 137.8 mm respectively) and October/November (132.6 mm, 339.6 mm respectively) record marginal rainfall events, whereas each of the months from December–

March (876 mm,909.8 mm, 932.6 mm, 986.4 mm) experience significant precipitation rates > 50% to the rest of the year (Figure 6). When considered alongside environmental factors, MA04 (April) is representative of being just after the start of the dry season and MA10 (October) represents the month just before the end of the dry season, conservatively marking the boundaries for the beginning and end of the dry season.

Etched vs non-etched samples

Seven archaeological shells were etched in HCL 10% (EA01–EA07) Five shells were not subjected to this treatment (A02–A06). This was in part to test the premise that the etching process increases the purity of the sample, making the value more precise (Jew et al. 2013). There was little variation between etched and non-etched shell, the greatest difference recorded being 0.58‰ for XU05 (Table 22), which is not unexpected as every shell will have slightly different values under the same conditions due to age and other factors. As such, where possible EA and A values were combined to depict the range of seasonality for each XU as was indicated by the δ^{18}O values. Only one value was available for MA04, MA10, XU01 and XU07 and these are depicted as single point (Figure 27).

XU #	Range ‰ δ^{18}O	Difference ‰
XU01	-4.48‰	0
XU02	-3.50– -3.06‰	0.44
XU03	-0.91 – -1.22 ‰	0.31
XU04	-2.60– -2.08 ‰	0.52
XU05	-1.65 – -2.24 ‰	0.58
XU06	-2.29 – -2.64‰	0.35
XU07	-1.43‰	0

Table 22 Range and difference of etched to non-etched archaeological shell values by XU

Seasonality within samples

The δ^{18}O values from terminal margins of multiple shells will express some variation, even if the shells are harvested from the same location at the same time. This is because molluscs grow at different rates over the course of a year. For this reason, they are usually discussed in terms of growth cycles, rather than age. Tropical shellfish are not exempt from this standard, however due to the marked differences between the wet and dry seasons, particularly in relation to precipitation events, it can be easier to determine age since these growth phases are more distinct. The sampling for this research did not require coverage of the entire shell span from umbo to terminal margin. Just over 50% of the shell was spot sampled with the expectation this would capture at least one full seasonal cycle of each shell, equated to one calendar year. It is clear in the values from most of these shells that this seasonal range was indeed recorded. Shellfish grow faster as juveniles and this rate decreases as they mature, meaning the overall age for each shell cannot be determined by the partial sampling conducted.

Seasonality and stratigraphy of SM:88

A key principal of this research is to determine the season that shells were harvested from the SM:88 archaeological site. This section interprets the $\delta^{18}O$ values obtained from the terminal margins of the modern and archaeological *M. hiantina* shell to indicate seasonality. These individual values indicate a minor level of variation around a central cluster; most lie within a band of -1.50–-3.00‰ $\delta^{18}O$ (MA04, MA10, XU04, XU05, XU06) and one (XU07) only marginally falls outside this band at -1.43‰ $\delta^{18}O$ (Figure 26, 27). The variability is far less within samples from a single XU (Figure 27). MA04 values indicate the $\delta^{18}O$ values recorded in April (-2.74‰ $\delta^{18}O$) at the end of the wet season.

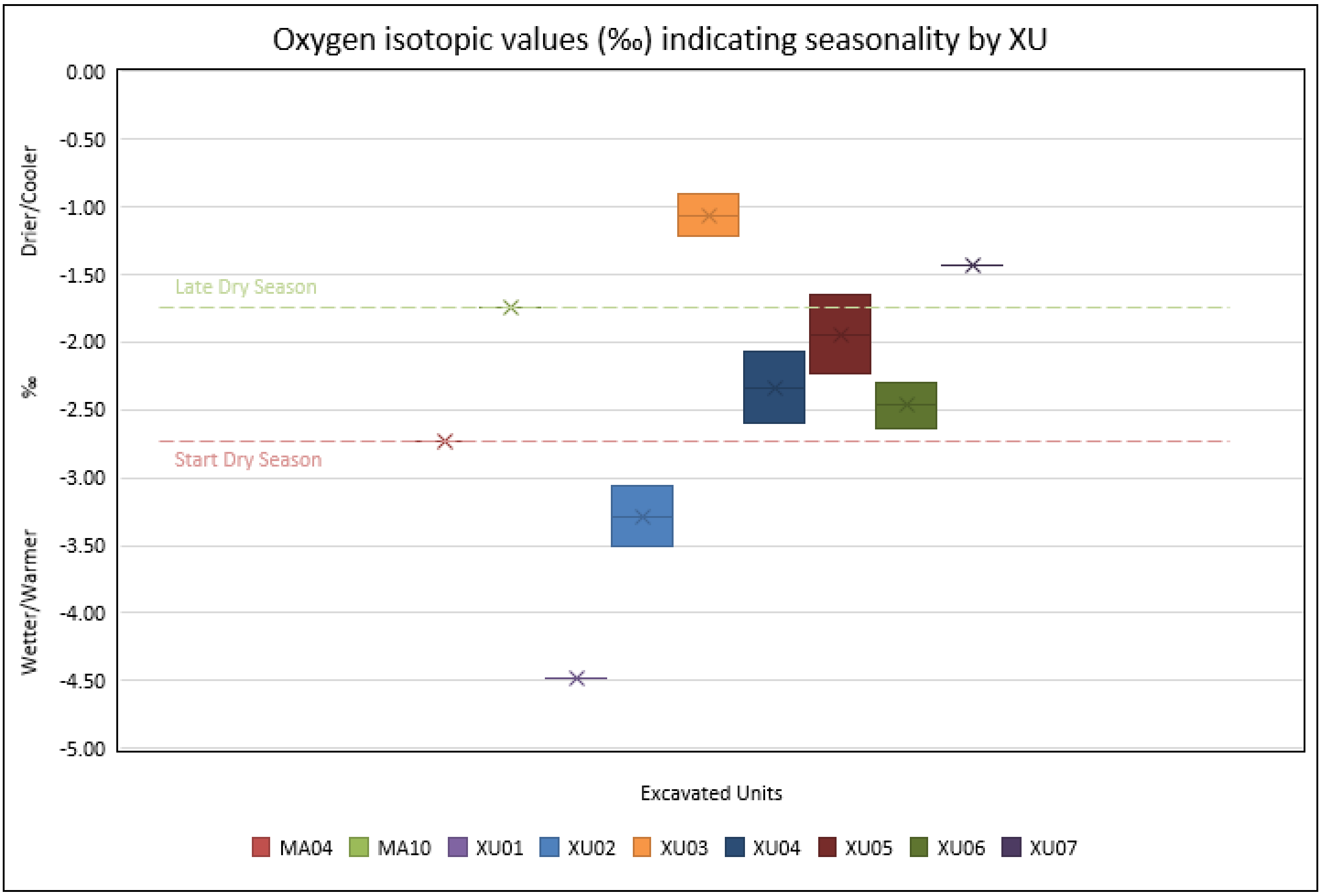

Figure 27 The seasonal range of shellfish harvest with corresponding XU, SM:88

The single value for XU01 (EA01, -4.48‰ $\delta^{18}O$) is from the upper, surface level of SM:88.

XU01 is the distinct outlier to the other values recorded, with a negative difference of - 1.75‰ δ^{18}O to MA04 marking a distinctly wetter and warm environment associated with the wet season. There are only two other values that record a figure lower than -3.00‰ δ^{18}O and they are both from XU02 (EA02, -3.50‰ δ^{18}O; A02, -3.06‰ δ^{18}O), with a negative difference to MA04 of 0.33–0.77‰. This difference is not great enough to confidently attribute XU02 to the wet season but could situate it within the transitional cusp from wet to dry season. The remainder of the excavated units all register values definitively placing them within the dry season (Table 23). XU03 records the highest values (EA03, -0.91‰ δ^{18}O; A03, -1.22‰ δ^{18}O) indicating that this shell was harvested under the coolest, driest conditions of all the shells sampled. The values for XU04 (EA04, -2.60‰ δ^{18}O, A04, -2.08‰ δ^{18}O), XU05 (EA05, -1.65‰ δ^{18}O, A05, -2.24‰ δ^{18}O), XU06 (EA06, - 2.29‰ δ^{18}O, A06, -2.64‰ δ^{18}O) and XU07 which had a single value (EA07, -1.43‰ δ^{18}O) are all situated between values for MA04 and MA10.

Dry	**MA04**	**MA10**			**XU03**	**XU04**	**XU05**	**XU06**	**XU07**
Cusp				**XU02**					
Wet			**XU01**						

Table 23 Seasonality of shellfish as indicated by δ^{18}O values

The transition to a wet season occupation suggested by the oxygen isotope values in XU01 corresponds with a significant decrease in the count of shellfish. There is no correlation between the terminal margin δ^{18}O values and changes in the cultural materials or composition of the shell and sediment stratigraphy in SM:88, making it apparent that conventional archaeological data cannot detect seasonality. XU01 records the smallest number of *M. hiantina* shell (%), with a decrease of almost 20% from XU02 but remains the dominant species (Table 4, Figure 4). However, this change is probably not significant as the species percentage is approximately the same as in XU04 or XU05 (Table 4, Figure 4).

The transition to a wet season subsistence also marked the final accumulation phase for SM:88. The age determination was collected from a depth of 21 cm, which indicates accumulation phases may have continued beyond this estimate and into the early colonial period, as has been shown for other sites in Albatross Bay, and at Prunung (Morrison 2014:6).

Implications for Australian models

This section assesses the implications of the seasonality findings against models for mound function and formation for northern Australia. The main consensus across seasonality models is that during the wet season people's mobility was reduced as a result of flooding and heavy rainfall (Twaddle t al. 2017:26). In response, they established bases or camps near coastal zones to exploit the plentiful resource-rich ecosystems and freshwater sources (Bailey 1977:140; Brockwell et al. 2013; Bourke 2012:139, Faulkner 2013 Meehan 1982:12, 58–80; Peterson 1973). The timing of seasonal occupation at SM:88 does seem to be connected to seasonal cycles, based on the returned $\delta^{18}O$ values. However, almost all the of $\delta^{18}O$ values point to a preference for occupation in the dry season, which stands in direct contrast to these wet season models. The exception to this preference is Layer A (XU01–XU02), which indicates wet and late-wet/dry cusp conditions.

For Abydos Coastal Plain in northern Western Australia, Clune and Harrison (2009) propose a seasonal cycle of mound formation which would likely show a similar isotopic pattern as is apparent in XU02 of SM:88. But again, the XU02 value is more of an anomaly than an indicator of preference. Clune and Harrison (2009) advocate that given the lack of associated cultural material these were not occupation sites but used in a similar fashion to Meehan's processing or dinnertime camps (Meehan1982:112–114). The lack of cultural materials recovered from SM:88 and many other shell mounds is consistent with the idea that these are not sites reflecting an increased sedentary lifestyle or occupation.

Baily (1977) and Faulkner (2013) advocate an increased occupation of coastal zones during the wet season to exploit marine resources. Morrison (2013a) holds that shell mounds were sites visited during the late-dry season, but not in response to environmental conditions or associated restrictions. He views these sites as places where people came together for short periods of time for shared community events such as ceremonial practices or marriages. These sites would have been selected on the basis of being able to procure a large volume of food over a short timeframe with relative ease. In terms of broad seasonal timing, the minimum number of individual (MNI) shellfish that corresponds with the dry season conditions supports this model. The season that recorded the wetter conditions was the same that registered a dramatic decrease in shell content (XU01).

Comparison to other studies

There are two other studies against which SM:88 can be compared. The timing of occupation in geographically different areas within central northern Australia appears to be linked to the late wet season according to stable oxygen analysis by Brockwell et al. (2013). The level of variability they recorded in some cases could be due to past heightened hydrological regimes, but to date it doesn't appear that these results have been revisited. They linked an increasing aridity to the depletion of suitable habitats for the shellfish, causing the cessation of mound accumulation phases (Brockwell et al. 2013:30). The cycle recorded for SM:88 is at complete odds with this model, as it was under the drier conditions that the shellfish was predominantly harvested. It must be noted that the driving questions for Brockwell et al. (2013) focused on climatic trends, rather than seasonality of harvest.

The stable isotope data from a site at Murdumurdu, Bentinck Island, in the southern Gulf of Carpentaria tied the seasonality of the shell midden to decisively dry season conditions (Twaddle et al. 2017:30). The midden was also *M. hiantina* dominant (Twaddle et al 2017:17) but was not of a depth that could be assessed for occupation patterns as it was relatively shallow (Twaddle et al. 2017:17). However, it has been modelled as a site for the targeting of a specific resource in relation to short-term occupation, which stands in agreement with the 'niche' model proposed by Morrison (2013a)

Conclusion

This section analyses and summarises the results of this research against the research aims and study results. It concludes by considering possible future research directions.

This research fills a gap in Australian archaeological research. While there have been many studies of shell mound seasonality in other countries (see Álvarez et al. 2011; Andrus 2011; Andrus and Thompson 2012; Brockwell et al. 2013; Burchell et al. 2013; Finstad et al. 2013; Hallmann et al. 2013; Harke 2015; Jew and Fitzpatrick 2015; Leng and Lewis 2016; Schöne and Gillikin 2013), this is the first study that has successfully determined shell mound seasonality in Cape York Peninsula, and one of a very limited few to do so in Australia (Twaddle 2016,). The success of this research is primarily due to a shift in focus away from the shellfish species *T. granosa*, which is widely considered the dominant species in shell matrix sites throughout northern Australia (Bailey 1999; Clune and Harrison 2009; Cochrane 2014; Falkner 2009, 2013; Morrison 2013a). Instead, this study focuses on the less dominant shellfish *M. hiantina*, which allowed for the collection and testing of modern specimens of the same species to provide a baseline for interpreting the archaeological shells. This is not possible for *T. granosa*.

Examination of current research regarding mounds and seasonality

The seasonality of shell mound construction in northern Australia is largely unknown. Archaeologists have developed models from ethnographic and historical documents, and environmental reconstructions. Many rely on conventional archaeology data, such as the presence or absence of migratory faunal remains, otoliths, or the seasonal peak of shellfish spawning events to make these judgements. On this basis most seasonality models for shellfish harvesting, mound use and formation in northern Australia propose a prolonged wet season occupation and subsistence strategy (Bailey 1997; Bourke 2012; Cribb 1991; Meehan 1982).

There are three notable exceptions. Firstly: Clune and Harrison (2009) argue that mounds at Abydos Coastal Plain in northern Western Australia were formed during the late wet / early dry season, involved short-term occupation only, and were driven by environmental factors that caused an increased dietary reliance on shellfish. Secondly, Morrison (2013a) proposes a late dry season occupation and exploitation of estuarine environments in connection with short-term mound building events at Albatross Bay, Cape York Peninsula. He bases this model on the lack of cultural material commonly recorded in shell matrix sites and the capacity for greater mobility, in contrast to wet season conditions, allowing for shared community events such as ceremonial practices and marriages to take place. Thirdly, Twaddle et al. (2017) use $\delta^{18}O$ values from *M. hiantina* shell to determine the short-term occupation of middens exclusively during the dry season at Murdumurdu, Bentinck Island, in the southern Gulf of Carpentaria.

Determining seasonality of SM:88 at Prunung, Weipa

The seasonal identification of shell mounds can be calculated by applying oxygen isotope analysis to shellfish. This technique was used to assess the seasonality of SM:88 at Prunung, Weipa. Spot sampling was applied to shell from the seven excavated units spanning three broad stratigraphic layers over a period of ~300 years. The results of the $\delta^{18}O$ analysis point to a distinct preference for a dry season occupation for the lower two layers. The $\delta^{18}O$ values for the upper, surface layer indicated a distinct transition to wetter season occupation.

Implications of a dry season occupation for models in northern Australia

The two recent applications of $\delta^{18}O$ analysis for analysing seasonality, presented here and in Twaddle et al. (2017), indicate dry season occupation. This contrasts with most models used to currently explain occupation and subsistence patterns of coastal zones in conjunction with shell matrix sites. It demonstrates that interpretations based on the composition of sediment and shellfish in stratigraphic layers and the presence or absence of migratory faunal remains are ill-equipped for determining seasonality. Models that rely on environmental reconstructions or ethnographic and historical documents are also potentially inadequate as they impose current human responses to change on societies millennia in the past. These data generate models too general to interrogate for seasonality. Bailey (1977) integrated personal observation, historical and ethnographic records and seasonal peaks of shellfish species for Albatross Bay for his model, and Faulkner (2013) based his on combined environmental reconstructions with seasonal peaks in shellfish species. Without the application of techniques such as $\delta^{18}O$, these models cannot be refined beyond theoretical frameworks.

Enhancing our understanding of Holocene subsistence and occupation in shell mound sites in northern Australia

This research focuses on one of 12 shell mound sites at Prunung, Weipa. As such, care must be taken not to extrapolate these results too widely. The determination of dry season occupation challenges models of wet season occupation and illustrates that human behaviour cannot be easily or adequately defined or rationalised by broad models. Human responses are nuanced, dynamic, adaptable and sometimes unpredictable. Broad models hide these intricacies by providing long-term models that trace only gross changes. $\delta^{18}O$ analysis is one of a number of techniques that allow for detailed investigations, such as seasonality determinations by individual stratigraphic layers, that can refine our interpretations of site use and occupation.

Further research

Future research would benefit from developing a database consisting of regular, monthly sampling of local $\delta^{18}O$ water values and modern specimens of the shellfish species being analysed. Ideally this would occur over several consecutive years to allow for variability between seasons. This would provide a detailed baseline for interpreting archaeological shell and understanding the effects of variable intra- and inter-seasonal hydrological regimes on shell at a local level.

A further consideration would be to compare the $\delta^{18}O$ values of multiple shell sites in one location or adjacent sites. Currently we know SM:88 was predominately occupied during the dry season. These results are based on just a few shells from each layer, which could potentially introduce bias. A more robust investigation with a more intensive sampling strategy would provide a more detailed interpretation of variability in the accumulation phases. If we conducted $\delta^{18}O$ analysis on the remaining 11 shell mounds at Prunung, we would be able to ascertain if these were used at the same time of the year, or if they were decidedly different. From this we could interpret whether shell mound use was generally congruent across a site, whether the same trends can be identified in older mounds or if mounds were used differently across the region at different periods of the year.

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APPENDICES

Appendices 1 XRD values

Attached here are raw data from a shell from XU01. Analysed was conducted over a two-minute run. The results are indicative of the values retrieved from all the *M. hiantina* shells.

SM88_XU01-001	
ID	667
10	3.1979166
10.01949	2.729167
10.03898	3.177083
10.05847	2.958333
10.07795	3.239583
10.09744	3.15625
10.11693	3.302083
10.13642	3.020833
10.15591	3.28125
10.1754	3.114583
10.19489	3.010417
10.21437	3.3125
10.23386	3.208333
10.25335	3.25
10.27284	3.21875
10.29233	2.833333
10.31182	3.020833
10.33131	3.166667
10.35079	2.947917
10.37028	3.208333
10.38977	3.010417
10.40926	3.333333
10.42875	3.03125
10.44824	2.927083
10.46773	2.875
10.48721	3.125
10.5067	3.239583
10.52619	2.802083
10.54568	3.333333
10.56517	3.541667
10.58466	3.03125
10.60415	3.135417
10.62363	3.28125
10.64312	3.21875
10.66261	3.239583
10.6821	3.0625

10.70159	3.59375
10.72108	3.135417
10.74057	3.291667
10.76005	3.166667
10.77954	3.03125
10.79903	3.177083
10.81852	3.572917
10.83801	2.96875
10.8575	3.40625
10.87699	3.041667
10.89647	3.041667
10.91596	3.291667
10.93545	3.552083
10.95494	3
10.97443	3.458333
10.99392	3.135417
11.01341	2.958333
11.03289	3.166667
11.05238	3.260417
11.07187	3.010417
11.09136	3.114583
11.11085	3.15625
11.13034	3.291667
11.14983	3.21875
11.16931	3.125
11.1888	3.21875
11.20829	2.875
11.22778	3
11.24727	2.9375
11.26676	3.25
11.28625	3.177083
11.30573	3.114583
11.32522	3.260417
11.34471	3.270833
11.3642	3.15625
11.38369	3.322917
11.40318	3.166667
11.42267	3.020833
11.44215	3.291667
11.46164	3.166667
11.48113	3.239583
11.50062	2.989583
11.52011	3.25
11.5396	3.177083
11.55908	2.916667
11.57857	3.427083

11.59806	3.354167
11.61755	3.0625
11.63704	3.229167
11.65653	3.354167
11.67602	3.135417
11.6955	3.46875
11.71499	3.197917
11.73448	3.239583
11.75397	2.9375
11.77346	3.239583
11.79295	3.09375
11.81244	3.229167
11.83192	3.354167
11.85141	3.166667
11.8709	3.083333
11.89039	3.479167
11.90988	3.010417
11.92937	3.21875
11.94886	3.09375
11.96834	2.958333
11.98783	3.041667
12.00732	3.260417
12.02681	3.197917
12.0463	3.114583
12.06579	2.833333
12.08528	3.270833
12.10476	3.020833
12.12425	2.645833
12.14374	3.239583
12.16323	3.270833
12.18272	3.125
12.20221	3.395833
12.2217	2.958333
12.24118	2.84375
12.26067	3.177083
12.28016	3.3125
12.29965	3.375
12.31914	3.479167
12.33863	3.364583
12.35812	3.145833
12.3776	2.739583
12.39709	3
12.41658	3.072917
12.43607	3.177083
12.45556	2.90625
12.47505	3.125

12.49454	2.802083
12.51402	3
12.53351	3.114583
12.553	3.40625
12.57249	2.489583
12.59198	3.40625
12.61147	2.979167
12.63096	3.375
12.65044	3.364583
12.66993	3.104167
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12.70891	3.302083
12.7284	3.114583
12.74789	3.166667
12.76738	2.885417
12.78686	3.03125
12.80635	3.145833
12.82584	3.104167
12.84533	3.208333
12.86482	3.072917
12.88431	2.791667
12.9038	3.4375
12.92328	3.041667
12.94277	3.083333
12.96226	3.270833
12.98175	3.020833
13.00124	2.916667
13.02073	3.135417
13.04022	3.427083
13.0597	3.125
13.07919	3.291667
13.09868	3.166667
13.11817	2.8125
13.13766	2.822917
13.15715	3.020833
13.17664	2.947917
13.19612	3.135417
13.21561	3.1875
13.2351	2.895833
13.25459	3.03125
13.27408	2.802083
13.29357	2.739583
13.31306	2.885417
13.33254	2.979167
13.35203	3.010417
13.37152	3.0625

13.39101	3.052083
13.4105	3.270833
13.42999	3.166667
13.44948	3.34375
13.46896	3.260417
13.48845	3.083333
13.50794	3.177083
13.52743	3.09375
13.54692	2.989583
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13.60538	2.708333
13.62487	3.145833
13.64436	3.020833
13.66385	3.010417
13.68334	3.1875
13.70283	2.8125
13.72232	3.020833
13.7418	2.9375
13.76129	3.114583
13.78078	2.895833
13.80027	2.989583
13.81976	2.989583
13.83925	2.958333
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13.87822	2.84375
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13.9172	3.177083
13.93669	2.739583
13.95618	2.895833
13.97567	3.260417
13.99516	3.302083
14.01464	2.833333
14.03413	3.15625
14.05362	2.90625
14.07311	2.739583
14.0926	2.822917
14.11209	2.947917
14.13158	2.8125
14.15106	3.114583
14.17055	2.677083
14.19004	2.885417
14.20953	3.0625
14.22902	2.958333
14.24851	2.802083
14.268	2.604167

14.28748	2.833333
14.30697	2.71875
14.32646	2.614583
14.34595	3.125
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14.38493	3.010417
14.40441	2.958333
14.4239	2.802083
14.44339	2.697917
14.46288	2.65625
14.48237	2.427083
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14.52135	2.90625
14.54083	2.71875
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14.63828	2.46875
14.65777	3.03125
14.67725	2.916667
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14.73572	2.583333
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14.7747	2.71875
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18.20468	1.96875
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18.24366	2.28125
18.26315	2.135417
18.28264	2.260417
18.30213	1.9375
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18.3411	1.802083
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18.45804	1.979167
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18.49701	2.21875
18.5165	1.916667
18.53599	2.270833
18.55548	2.239583
18.57497	2.114583
18.59446	2.083333
18.61394	2.260417
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18.6919	2.052083
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18.75036	1.958333

18.76985	1.895833
18.78934	2.125
18.80883	1.895833
18.82832	1.927083
18.84781	1.96875
18.8673	1.989583
18.88678	1.90625
18.90627	2.041667
18.92576	1.96875
18.94525	1.802083
18.96474	1.958333
18.98423	2.03125
19.00372	1.947917
19.0232	2.072917
19.042692720892	0.25
19.06218	1.864583
19.08167	2
19.10116	1.8125
19.12065	2.010417
19.14014	1.979167
19.15962	1.635417
19.17911	1.958333
19.1986	2.104167
19.21809	1.90625
19.23758	1.90625
19.25707	1.677083
19.27656	2.03125
19.29604	1.916667
19.31553	2.135417
19.33502	1.760417
19.35451	1.90625
19.374	1.9375
19.39349	1.875
19.41298	1.96875
19.43246	1.760417
19.45195	2.020833
19.47144	1.739583
19.49093	1.802083
19.51042	1.854167
19.52991	1.947917
19.5494	2.041667
19.56888	1.864583
19.58837	1.729167
19.60786	1.541667
19.62735	1.979167
19.64684	1.802083

19.66633	1.895833
19.68582	1.927083
19.7053	1.96875
19.72479	1.8125
19.74428	1.8125
19.76377	1.802083
19.78326	1.895833
19.80275	1.927083
19.82224	1.645833
19.84172	1.677083
19.86121	1.729167
19.8807	1.65625
19.90019	1.833333
19.91968	1.770833
19.93917	1.708333
19.95866	1.635417
19.97814	1.75
19.99763	1.947917
20.01712	1.864583
20.03661	1.760417
20.0561	1.96875
20.07559	1.71875
20.09508	1.5625
20.11456	1.635417
20.13405	1.552083
20.15354	1.75
20.17303	2.010417
20.19252	1.802083
20.21201	1.697917
20.23149	1.708333
20.25098	1.552083
20.27047	1.708333
20.28996	1.739583
20.30945	1.864583
20.32894	1.645833
20.34843	1.6875
20.36791	1.78125
20.3874	1.177083
20.40689	1.729167
20.42638	1.760417
20.44587	1.760417
20.46536	1.65625
20.48485	1.927083
20.50433	1.864583
20.52382	1.854167
20.54331	1.6875

20.5628	1.583333
20.58229	1.802083
20.60178	1.71875
20.62127	1.708333
20.64075	1.666667
20.66024	1.729167
20.67973	1.604167
20.699220482261	0.65625
20.71871	1.520833
20.7382	1.84375
20.75769	1.5
20.77717	1.760417
20.79666	1.697917
20.81615	1.75
20.83564	1.708333
20.85513	1.666667
20.87462	1.708333
20.89411	1.645833
20.91359	1.5
20.93308	1.791667
20.95257	1.510417
20.97206	1.625
20.99155	1.770833
21.01104	1.677083
21.03053	1.5
21.05001	1.59375
21.0695	1.604167
21.08899	1.520833
21.10848	1.645833
21.12797	1.583333
21.14746	1.552083
21.16695	1.739583
21.18643	1.802083
21.20592	1.583333
21.22541	1.604167
21.2449	1.65625
21.26439	1.791667
21.28388	1.614583
21.30337	1.572917
21.32285	1.5625
21.34234	1.40625
21.36183	1.572917
21.38132	1.395833
21.40081	1.520833
21.4203	1.71875
21.43979	1.65625

21.45927	1.479167
21.47876	1.854167
21.49825	1.822917
21.51774	1.75
21.53723	1.59375
21.55672	1.375
21.57621	1.802083
21.59569	1.520833
21.61518	1.614583
21.63467	1.447917
21.65416	1.833333
21.67365	1.677083
21.69314	1.645833
21.71263	1.375
21.73211	1.53125
21.7516	1.697917
21.77109	1.78125
21.79058	1.59375
21.81007	1.479167
21.82956	1.458333
21.84905	1.822917
21.86853	1.427083
21.88802	1.40625
21.90751	1.59375
21.927	1.645833
21.94649	1.447917
21.96598	1.65625
21.98547	1.604167
22.00495	1.5
22.02444	1.635417
22.04393	1.583333
22.06342	1.395833
22.08291	1.5
22.1024	1.65625
22.12189	1.71875
22.14137	1.677083
22.16086	1.666667
22.18035	1.541667
22.19984	1.697917
22.21933	1.947917
22.23882	1.447917
22.25831	1.5625
22.27779	1.53125
22.29728	1.614583
22.31677	1.552083
22.33626	1.697917

22.35575	1.666667
22.37524	1.5625
22.39473	1.5
22.41421	1.583333
22.4337	1.541667
22.45319	1.5
22.47268	1.5
22.49217	1.552083
22.51166	1.541667
22.53115	1.40625
22.55063	1.572917
22.57012	1.510417
22.58961	1.520833
22.609099548311	0.541667
22.62859	1.604167
22.64808	1.458333
22.66757	1.53125
22.68705	1.583333
22.70654	1.520833
22.72603	1.447917
22.74552	1.364583
22.76501	1.427083
22.7845	1.479167
22.80399	1.416667
22.82347	1.458333
22.84296	1.333333
22.86245	1.375
22.88194	1.458333
22.90143	1.552083
22.92092	1.427083
22.94041	1.489583
22.95989	1.552083
22.97938	1.291667
22.99887	1.447917
23.01836	1.84375
23.03785	1.78125
23.05734	1.645833
23.07683	1.354167
23.09631	1.552083
23.1158	1.614583
23.13529	1.770833
23.15478	1.5
23.17427	1.583333
23.19376	1.46875
23.21324	1.416667
23.23273	1.510417

23.25222	1.625
23.27171	1.479167
23.2912	1.427083
23.31069	1.239583
23.33018	1.34375
23.34966	1.25
23.36915	1.458333
23.38864	1.447917
23.40813	1.520833
23.42762	1.385417
23.44711	1.322917
23.4666	1.614583
23.48608	1.520833
23.50557	1.53125
23.52506	1.510417
23.54455	1.375
23.56404	1.260417
23.58353	1.583333
23.60302	1.572917
23.6225	1.46875
23.64199	1.28125
23.66148	1.25
23.68097	1.260417
23.70046	1.385417
23.71995	1.25
23.73944	1.333333
23.75892	1.479167
23.77841	1.3125
23.7979	1.416667
23.81739	1.395833
23.83688	1.145833
23.85637	1.354167
23.87586	1.322917
23.89534	1.416667
23.91483	1.40625
23.93432	1.21875
23.95381	1.375
23.9733	1.260417
23.99279	1.541667
24.01228	1.25
24.03176	1.385417
24.05125	1.614583
24.07074	1.364583
24.09023	1.427083
24.10972	1.364583
24.12921	1.322917

24.1487	1.479167
24.16818	1.364583
24.18767	1.354167
24.20716	1.21875
24.22665	1.322917
24.24614	1.34375
24.265627309681	0.552083
24.28512	1.177083
24.3046	1.541667
24.32409	1.46875
24.34358	1.447917
24.36307	1.53125
24.38256	1.177083
24.40205	1.510417
24.42154	1.354167
24.44102	1.354167
24.46051	1.229167
24.48	1.46875
24.49949	1.864583
24.51898	1.604167
24.53847	2.09375
24.55796	1.927083
24.57744	2.15625
24.59693	1.958333
24.61642	1.770833
24.63591	1.666667
24.6554	1.760417
24.67489	1.416667
24.69438	1.510417
24.71386	1.260417
24.73335	1.40625
24.75284	1.447917
24.77233	1.302083
24.79182	1.239583
24.81131	1.28125
24.8308	1.5625
24.85028	1.197917
24.86977	1.291667
24.88926	1.395833
24.90875	1.4375
24.92824	1.239583
24.94773	1.15625
24.96722	1.354167
24.9867	1.25
25.00619	1.4375
25.02568	1.197917

25.04517	1.666667
25.06466	1.145833
25.08415	1.302083
25.10364	1.114583
25.12312	1.229167
25.14261	1.208333
25.1621	1.302083
25.18159	1.395833
25.20108	1.4375
25.22057	1.364583
25.24006	1.166667
25.25954	1.208333
25.27903	1.239583
25.29852	1.385417
25.31801	1.416667
25.3375	1.03125
25.35699	1.28125
25.37648	1.125
25.39596	1.260417
25.41545	1.28125
25.43494	1.114583
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25.47392	1.083333
25.49341	1.385417
25.5129	1.1875
25.53238	1.3125
25.55187	1.322917
25.57136	1.020833
25.59085	1.197917
25.61034	1.21875
25.62983	1.291667
25.64932	1.166667
25.6688	1.3125
25.68829	1.145833
25.70778	1.322917
25.72727	1.229167
25.74676	1.1875
25.76625	1.291667
25.78574	1.302083
25.80522	1.1875
25.82471	1.260417
25.8442	1.260417
25.86369	1.270833
25.88318	1.145833
25.90267	1.270833
25.92216	1.291667

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25.96113	1.34375
25.98062	1.5
26.00011	1.375
26.0196	1.354167
26.03909	1.40625
26.05858	1.3125
26.07806	1.302083
26.09755	1.25
26.11704	1.322917
26.13653	1.020833
26.15602	1.302083
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26.19499	1.21875
26.21448	1.125
26.23397	1.364583
26.25346	1.104167
26.27295	1.291667
26.29244	1.208333
26.31193	1.135417
26.33141	1.083333
26.3509	1.1875
26.37039	1.177083
26.38988	1.239583
26.40937	1.104167
26.42886	1.125
26.44835	1.15625
26.46783	1.1875
26.48732	1.177083
26.50681	1.09375
26.5263	1.239583
26.54579	0.979167
26.56528	1.364583
26.58477	1.083333
26.60425	1.166667
26.62374	1.010417
26.64323	1.395833
26.66272	1.177083
26.68221	1.229167
26.7017	1.21875
26.72119	1.0625
26.74067	1.145833
26.76016	1.28125
26.77965	1.270833
26.79914	1.40625
26.81863	1.25

26.83812	1.291667
26.85761	1.208333
26.87709	1.3125
26.89658	1.083333
26.91607	1.1875
26.93556	1.104167
26.95505	1.208333
26.97454	1.208333
26.99403	1.21875
27.01351	1.135417
27.033	1.25
27.05249	1.302083
27.07198	1.177083
27.09147	1.083333
27.11096	1.354167
27.13045	1.083333
27.14993	1.114583
27.16942	1.020833
27.18891	1.041667
27.2084	1.114583
27.22789	1.322917
27.24738	1.145833
27.26687	1.1875
27.28635	0.989583
27.30584	1.052083
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27.34482	1.177083
27.36431	1.197917
27.3838	1.53125
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27.42277	1.28125
27.44226	1.072917
27.46175	1.052083
27.48124	1.15625
27.50073	1.25
27.52022	1.385417
27.53971	1.552083
27.55919	1.34375
27.57868	1.6875
27.59817	1.760417
27.61766	1.708333
27.63715	1.947917
27.65664	1.65625
27.67613	1.989583
27.69561	1.833333
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27.75408	1.28125
27.77357	1.333333
27.79306	1.291667
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27.85152	1.260417
27.87101	1.145833
27.8905	1.416667
27.90999	1.197917
27.92948	1.145833
27.94897	1.21875
27.96845	1.041667
27.98794	1.125
28.00743	0.989583
28.02692	1.114583
28.04641	1.322917
28.0659	1.052083
28.08539	1.166667
28.10487	1.072917
28.12436	1.166667
28.14385	1.25
28.16334	1.125
28.18283	1.208333
28.20232	1.104167
28.22181	1.177083
28.24129	1.010417
28.26078	1.229167
28.28027	1.260417
28.29976	1.177083
28.31925	1.052083
28.33874	1.135417
28.35823	1.15625
28.37771	1.1875
28.3972	1.177083
28.41669	1.333333
28.43618	1.260417
28.45567	1.125
28.47516	1.15625
28.49465	1.25
28.51413	1.114583
28.53362	1.104167
28.55311	1.302083
28.5726	1.09375
28.59209	1.25
28.61158	1.197917

28.63107	1.4375
28.65055	1.40625
28.67004	1.447917
28.68953	1.645833
28.70902	1.71875
28.72851	1.416667
28.748	1.333333
28.76749	1.71875
28.78697	1.479167
28.80646	1.166667
28.82595	1.322917
28.84544	1.427083
28.86493	1.260417
28.88442	1.270833
28.90391	1.177083
28.92339	1.083333
28.94288	1.0625
28.96237	1.260417
28.98186	0.958333
29.00135	1.135417
29.02084	1.166667
29.04032	1.21875
29.05981	1.28125
29.0793	1.3125
29.09879	1.125
29.11828	1.208333
29.13777	1.09375
29.15726	1.125
29.17674	1.197917
29.19623	1.09375
29.21572	1.135417
29.23521	1.104167
29.2547	1.125
29.27419	1.302083
29.29368	1.125
29.31316	1.083333
29.33265	1.03125
29.35214	1.083333
29.37163	1.197917
29.39112	1.125
29.41061	1.09375
29.4301	1.177083
29.44958	1.208333
29.46907	1.15625
29.48856	1.15625
29.50805	1.270833

29.52754	1.322917
29.54703	1.052083
29.56652	1.15625
29.586	1.28125
29.60549	1.322917
29.62498	1.260417
29.64447	1.125
29.66396	1.25
29.68345	1.270833
29.70294	1.145833
29.72242	1.15625
29.741913203151	0.229167
29.7614	1.239583
29.78089	1.364583
29.80038	1.177083
29.81987	1.510417
29.83936	1.1875
29.85884	1.302083
29.87833	1.395833
29.89782	1.46875
29.91731	1.3125
29.9368	1.510417
29.95629	1.28125
29.97578	1.34375
29.99526	1.46875
30.01475	1.489583
30.03424	1.510417
30.05373	1.385417
30.07322	1.541667
30.09271	1.4375
30.1122	1.583333
30.13168	1.739583
30.15117	1.833333
30.17066	2.010417
30.19015	2.020833
30.20964	2.135417
30.22913	2.260417
30.24862	2.260417
30.2681	2.197917
30.28759	2.479167
30.30708	2.791667
30.32657	3.03125
30.34606	3.364583
30.36555	3.916667
30.38504	4.291667
30.40452	4.5625

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30.4435	6.46875
30.46299	7.916667
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30.50197	12.89583
30.52146	16.4375
30.54094	19.875
30.56043	23.38542
30.57992	24.83333
30.59941	24.84375
30.6189	25.0625
30.63839	22.55208
30.65788	20.54167
30.67736	17.23958
30.69685	13.91667
30.71634	11.36458
30.73583	9.552083
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30.7943	5.833333
30.81378	4.958333
30.83327	4.427083
30.85276	3.916667
30.87225	3.9375
30.89174	3.541667
30.91123	4.020833
30.93072	3.28125
30.9502	2.645833
30.96969	2.666667
30.98918	2.447917
31.00867	2.708333
31.02816	2.729167
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31.10611	2.489583
31.1256	2.427083
31.14509	2.135417
31.16458	2.052083
31.18407	1.895833
31.20356	2.0625
31.22304	2.020833
31.24253	1.802083
31.26202	2.072917
31.28151	2.177083
31.301	2.114583

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31.33998	2.03125
31.35946	2.333333
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31.43742	2.302083
31.45691	2.34375
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31.49588	2.666667
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31.53486	3.15625
31.55435	3.479167
31.57384	3.59375
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31.61282	4.020833
31.6323	4.6875
31.65179	5.239583
31.67128	6.958333
31.69077	7.989583
31.71026	9.84375
31.72975	12.07292
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31.76872	14.05208
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31.82719	11.90625
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31.86617	8.5
31.88566	7.4375
31.90514	6.291667
31.92463	5.197917
31.94412	4.354167
31.96361	3.9375
31.9831	3.46875
32.00259	2.864583
32.02207	2.708333
32.04156	2.75
32.06105	2.291667
32.08054	1.927083
32.10003	1.8125
32.11952	1.760417
32.13901	1.770833
32.15849	1.791667
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32.19747	1.489583

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32.27543	1.375
32.29491	1.3125
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32.33389	1.09375
32.35338	1.145833
32.37287	1.125
32.39236	1.229167
32.41185	1.385417
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32.45082	1.34375
32.47031	0.84375
32.4898	1.0625
32.50929	1.104167
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32.56775	1.239583
32.58724	1.020833
32.60673	1.177083
32.62622	1.125
32.64571	1.041667
32.6652	1.0625
32.68469	1.1875
32.70417	1.177083
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32.76264	1.114583
32.78213	0.927083
32.80162	1.072917
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32.84059	0.916667
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32.89906	0.895833
32.91855	1.166667
32.93804	0.947917
32.95753	0.895833
32.97701	1.072917
32.9965	0.9375
33.01599	0.916667
33.03548	0.96875
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33.07446	0.9375
33.09395	1.0625

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33.13292	0.854167
33.15241	1.03125
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33.23037	1.0625
33.24985	0.989583
33.26934	0.947917
33.28883	0.8125
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33.32781	1.041667
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33.46423	1.010417
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33.50321	1.072917
33.52269	0.875
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33.73707	1.0625
33.75656	0.916667
33.77605	0.8125
33.79553	0.9375
33.81502	1.020833
33.83451	1.052083
33.854	1.072917
33.87349	1.03125
33.89298	1.1875
33.91247	0.979167
33.93195	0.885417
33.95144	1.135417
33.97093	1.145833
33.99042	1.239583

34.00991	0.979167
34.0294	1.09375
34.04889	1.28125
34.06837	1.4375
34.08786	1.25
34.10735	1.239583
34.12684	1.3125
34.14633	1.260417
34.16582	1.53125
34.18531	1.208333
34.20479	1.177083
34.22428	1.135417
34.24377	1.208333
34.26326	1.302083
34.28275	1.3125
34.30224	1.34375
34.32173	1.291667
34.34121	1.239583
34.3607	1.21875
34.38019	1.458333
34.39968	1.291667
34.41917	1.197917
34.43866	1.40625
34.45815	1.3125
34.47763	1.197917
34.49712	1.416667
34.51661	1.489583
34.5361	1.333333
34.55559	1.1875
34.57508	1.229167
34.59457	1.1875
34.61405	1.447917
34.63354	1
34.65303	1.166667
34.67252	0.958333
34.69201	0.979167
34.7115	1.114583
34.73099	1.03125
34.75047	1.03125
34.76996	1.135417
34.78945	1.041667
34.80894	1.041667
34.82843	0.833333
34.84792	1.145833
34.8674	1.322917
34.88689	1.197917

34.90638	1.166667
34.92587	1.229167
34.94536	1.322917
34.964847791941	0.322917
34.98434	1.25
35.00382	1.239583
35.02331	1.03125
35.0428	1.104167
35.06229	1.114583
35.08178	1.135417
35.10127	0.947917
35.12076	0.84375
35.14024	1
35.15973	0.989583
35.17922	1.114583
35.19871	0.8125
35.2182	0.885417
35.23769	0.78125
35.25718	0.958333
35.27666	1
35.29615	0.75
35.31564	0.875
35.33513	0.729167
35.35462	0.895833
35.37411	0.822917
35.3936	0.8125
35.41308	0.885417
35.43257	0.635417
35.45206	0.833333
35.47155	0.697917
35.49104	0.791667
35.51053	0.854167
35.53002	0.8125
35.5495	0.90625
35.56899	0.708333
35.58848	0.791667
35.60797	0.770833
35.62746	0.78125
35.64695	0.90625
35.66644	0.979167
35.68592	0.895833
35.70541	0.864583
35.7249	0.802083
35.74439	0.760417
35.76388	0.697917
35.78337	0.739583

35.80286	0.791667
35.82234	0.84375
35.84183	0.895833
35.86132	0.9375
35.88081	0.802083
35.9003	0.708333
35.91979	0.916667
35.93928	0.822917
35.95876	1.010417
35.97825	0.8125
35.99774	0.75
36.01723	0.8125
36.03672	0.947917
36.05621	0.947917
36.0757	0.916667
36.09518	1.072917
36.11467	0.864583
36.13416	0.791667
36.15365	0.90625
36.17314	1.010417
36.19263	1.083333
36.21212	0.927083
36.2316	1.03125
36.25109	1.333333
36.27058	1.354167
36.29007	1.697917
36.30956	1.739583
36.32905	1.90625
36.34854	1.40625
36.36802	1.697917
36.38751	1.6875
36.407	1.59375
36.42649	1.583333
36.44598	1.4375
36.46547	1.4375
36.48496	1.104167
36.50444	0.885417
36.52393	1.177083
36.54342	1.145833
36.56291	1.020833
36.5824	0.90625
36.60189	1.020833
36.62138	0.916667
36.64086	0.9375
36.66035	0.927083
36.67984	0.802083

36.69933	0.697917
36.71882	0.9375
36.73831	0.614583
36.7578	0.90625
36.77728	0.875
36.79677	0.635417
36.81626	0.802083
36.83575	0.947917
36.85524	0.895833
36.874726857990	0.791667
36.89422	0.791667
36.9137	0.802083
36.93319	0.864583
36.95268	0.625
36.97217	0.729167
36.99166	0.78125
37.01115	0.729167
37.03064	0.989583
37.05012	0.708333
37.06961	0.9375
37.0891	0.84375
37.10859	0.864583
37.12808	0.71875
37.14757	0.65625
37.16706	0.854167
37.18654	0.864583
37.20603	0.729167
37.22552	0.708333
37.24501	0.625
37.2645	0.802083
37.28399	0.729167
37.30348	0.947917
37.32296	0.791667
37.34245	0.71875
37.36194	0.895833
37.38143	0.760417
37.40092	0.6875
37.42041	0.958333
37.4399	0.84375
37.45938	1.03125
37.47887	0.885417
37.49836	0.791667
37.51785	0.822917
37.53734	0.770833
37.55683	0.75
37.57632	0.90625

37.5958	0.802083
37.61529	0.822917
37.63478	1
37.65427	0.947917
37.67376	0.802083
37.69325	0.958333
37.71274	1.03125
37.73222	1.03125
37.75171	0.927083
37.7712	0.916667
37.79069	1
37.81018	0.96875
37.82967	1.09375
37.84915	1.208333
37.86864	0.90625
37.88813	1
37.90762	1.020833
37.92711	1.145833
37.9466	1.270833
37.96609	1.208333
37.98557	1.3125
38.00506	1.239583
38.02455	1.145833
38.04404	1.53125
38.06353	1.541667
38.08302	1.552083
38.10251	1.75
38.12199	1.635417
38.14148	1.96875
38.16097	2.28125
38.18046	2.1875
38.19995	2.354167
38.21944	2.927083
38.23893	3.09375
38.25841	2.770833
38.2779	3.197917
38.29739	3.041667
38.31688	3.25
38.33637	3.375
38.35586	2.885417
38.37535	2.78125
38.39483	2.666667
38.41432	2.572917
38.43381	2.958333
38.4533	2.739583
38.47279	2.583333

38.49228	2.697917
38.51177	3.03125
38.531254619363	0.010417
38.55074	3.625
38.57023	3.78125
38.58972	4.822917
38.60921	5.604167
38.6287	6.416667
38.64819	8.395833
38.66767	10.33333
38.68716	11.83333
38.70665	12.59375
38.72614	12.63542
38.74563	12.47917
38.76512	12.09375
38.78461	10.73958
38.80409	9.729167
38.82358	8.125
38.84307	6.989583
38.86256	5.802083
38.88205	5.166667
38.90154	4.135417
38.92103	4.03125
38.94051	3.25
38.96	2.583333
38.97949	2.697917
38.99898	2.364583
39.01847	2.125
39.03796	1.84375
39.05745	1.875
39.07693	1.697917
39.09642	1.854167
39.11591	1.822917
39.1354	1.583333
39.15489	1.25
39.17438	1.625
39.19387	1.208333
39.21335	1.489583
39.23284	1.25
39.25233	1.104167
39.27182	1.322917
39.29131	1.239583
39.3108	1.260417
39.33029	1.15625
39.34977	1.145833
39.36926	1.083333

39.38875	1.229167
39.40824	1.114583
39.42773	1.03125
39.44722	1.09375
39.46671	1.145833
39.48619	0.979167
39.50568	0.90625
39.52517	1.010417
39.54466	0.989583
39.56415	0.708333
39.58364	0.78125
39.60313	0.802083
39.62261	0.9375
39.6421	1.0625
39.66159	1.104167
39.68108	1.0625
39.70057	0.9375
39.72006	0.958333
39.73955	0.958333
39.75903	1
39.77852	0.916667
39.79801	1.09375
39.8175	1.041667
39.83699	1
39.85648	0.989583
39.87597	0.84375
39.89545	1.03125
39.91494	0.979167
39.93443	1.010417
39.95392	1.010417
39.97341	1.145833
39.9929	0.9375
40.01239	1.010417
40.03187	1.145833
40.05136	0.927083
40.07085	0.895833
40.09034	0.885417
40.10983	1.041667
40.12932	1.15625
40.14881	0.791667
40.16829	0.9375
40.18778	0.833333
40.20727	0.989583
40.22676	0.885417
40.24625	0.71875
40.26574	0.947917

40.28523	0.895833
40.30471	0.770833
40.3242	0.90625
40.34369	0.927083
40.36318	0.8125
40.38267	1.041667
40.40216	0.84375
40.42165	0.90625
40.441133685410	0.864583
40.46062	0.864583
40.48011	0.84375
40.4996	0.9375
40.51909	1.052083
40.53858	0.854167
40.55807	0.9375
40.57755	0.979167
40.59704	1
40.61653	0.979167
40.63602	1
40.65551	0.9375
40.675	0.833333
40.69448	1.020833
40.71397	1.020833
40.73346	0.885417
40.75295	1.083333
40.77244	1.270833
40.79193	1.239583
40.81142	0.8125
40.8309	1.020833
40.85039	0.958333
40.86988	1.083333
40.88937	0.802083
40.90886	0.9375
40.92835	1.09375
40.94784	0.875
40.96732	0.927083
40.98681	0.927083
41.0063	0.9375
41.02579	0.729167
41.04528	0.885417
41.06477	0.864583
41.08426	0.760417
41.10374	0.802083
41.12323	0.822917
41.14272	1.03125
41.16221	1.072917

41.1817	0.739583
41.20119	0.947917
41.22068	0.895833
41.24016	0.947917
41.25965	0.947917
41.27914	0.96875
41.29863	0.979167
41.31812	0.885417
41.33761	0.885417
41.3571	1.15625
41.37658	0.875
41.39607	0.916667
41.41556	0.927083
41.43505	0.90625
41.45454	1.125
41.47403	1.052083
41.49352	1
41.513	0.854167
41.53249	0.833333
41.55198	1.041667
41.57147	0.927083
41.59096	0.96875
41.61045	0.989583
41.62994	1.010417
41.64942	1.020833
41.66891	1.010417
41.6884	1.1875
41.70789	1.083333
41.72738	1.28125
41.74687	1.114583
41.76636	1.0625
41.78584	1.260417
41.80533	1.125
41.82482	1.15625
41.84431	1.3125
41.8638	1.583333
41.88329	1.479167
41.90278	1.510417
41.92226	1.614583
41.94175	1.822917
41.96124	1.739583
41.98073	1.916667
42.00022	2.041667
42.01971	1.96875
42.0392	2.3125
42.05868	2.552083

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42.11715	3.760417
42.13664	3.854167
42.15613	5.010417
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42.21459	7.614583
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42.25357	8.552083
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42.29255	9.614583
42.31204	9.333333
42.33152	7.895833
42.35101	7.927083
42.3705	7.197917
42.38999	6.364583
42.40948	5.541667
42.42897	5.333333
42.44846	4.15625
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42.48743	3.291667
42.50692	2.90625
42.52641	2.395833
42.5459	2.46875
42.56539	2.197917
42.58488	2.125
42.60436	1.875
42.62385	1.770833
42.64334	1.708333
42.66283	1.583333
42.68232	1.614583
42.70181	1.447917
42.7213	1.270833
42.74078	1.458333
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42.77976	1.052083
42.79925	1.270833
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42.83823	1.15625
42.85772	1.260417
42.8772	1.229167
42.89669	1.010417
42.91618	1.1875
42.93567	1.25
42.95516	1.104167

42.97465	1.177083
42.99414	1.041667
43.01362	0.927083
43.03311	1.125
43.0526	1.229167
43.07209	1.197917
43.09158	1.125
43.11107	0.9375
43.13056	1.135417
43.15004	1.28125
43.16953	1.020833
43.18902	1.0625
43.20851	1.135417
43.228	1.197917
43.24749	1.291667
43.26698	1.020833
43.28646	1.104167
43.30595	1.166667
43.32544	1.260417
43.34493	1.4375
43.36442	1.333333
43.38391	1.354167
43.4034	1.25
43.42288	1.4375
43.44237	1.729167
43.46186	1.71875
43.48135	1.9375
43.50084	2.385417
43.52033	2.40625
43.53982	2.65625
43.5593	2.90625
43.57879	4.15625
43.59828	4.166667
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43.63726	4.041667
43.65675	3.65625
43.67623	3.791667
43.69572	3.760417
43.71521	3.739583
43.7347	3.1875
43.75419	2.885417
43.77368	2.541667
43.79317	2.46875
43.81265	1.96875
43.83214	2.09375
43.85163	2.25

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43.9101	1.84375
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43.94907	1.729167
43.96856	1.666667
43.98805	1.65625
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44.04652	1.854167
44.06601	2.1875
44.08549	2.052083
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44.12447	2.385417
44.14396	2.614583
44.16345	2.53125
44.18294	3.229167
44.20243	3.510417
44.22191	3.927083
44.2414	5.010417
44.26089	5.8125
44.28038	6.34375
44.29987	8.28125
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44.33885	9.520833
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44.51424	4.53125
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44.55322	3.677083
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44.61169	2.895833
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44.76759	3.0625
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44.86504	3.666667
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45.19634	6.145833
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45.23532	5.510417
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45.70305	1.208333
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45.74202	0.927083
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45.781	0.854167
45.80049	1.010417
45.81998	1.114583
45.83947	1.010417
45.85895	0.833333
45.87844	0.96875
45.89793	0.96875
45.91742	0.8125
45.93691	0.927083
45.9564	0.864583
45.97589	0.833333
45.99537	1.114583
46.01486	0.739583
46.03435	1.010417
46.05384	1.03125
46.07333	0.885417
46.09282	0.802083
46.11231	0.739583
46.13179	0.9375
46.15128	0.791667
46.17077	0.833333
46.19026	0.875
46.20975	0.958333
46.22924	0.802083
46.24873	0.958333
46.26821	0.895833
46.2877	0.760417
46.30719	0.75
46.32668	0.770833
46.34617	0.802083
46.36566	0.84375
46.38515	0.760417
46.40463	0.677083
46.42412	0.854167
46.44361	0.729167
46.4631	0.614583
46.48259	0.875
46.50208	0.645833
46.52156	0.5625
46.54105	0.8125

46.56054	0.84375
46.58003	0.697917
46.59952	0.614583
46.61901	0.697917
46.6385	0.645833
46.65798	0.760417
46.67747	0.708333
46.69696	0.697917
46.71645	0.677083
46.73594	0.75
46.75543	0.708333
46.77492	0.75
46.7944	0.729167
46.81389	0.802083
46.83338	0.552083
46.85287	0.65625
46.87236	0.65625
46.89185	0.6875
46.91134	0.708333
46.93082	0.604167
46.95031	0.645833
46.9698	0.65625
46.98929	0.65625
47.00878	0.677083
47.02827	0.5
47.04776	0.760417
47.06724	0.75
47.08673	0.572917
47.10622	0.59375
47.12571	0.635417
47.1452	0.708333
47.16469	0.635417
47.18418	0.677083
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47.26213	0.635417
47.28162	0.583333
47.30111	0.864583
47.3206	0.770833
47.34008	0.552083
47.35957	0.6875
47.37906	0.541667
47.39855	0.78125
47.41804	0.8125
47.43753	0.614583

47.45702	0.770833
47.4765	0.71875
47.49599	0.6875
47.51548	0.875
47.53497	0.802083
47.55446	0.770833
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47.59344	0.885417
47.61292	0.739583
47.63241	0.791667
47.6519	0.6875
47.67139	0.760417
47.69088	0.760417
47.71037	0.697917
47.72986	0.8125
47.74934	0.729167
47.76883	0.71875
47.78832	0.729167
47.80781	0.78125
47.8273	0.802083
47.84679	0.979167
47.86628	0.854167
47.88576	0.875
47.90525	1.083333
47.92474	0.989583
47.94423	0.927083
47.96372	0.947917
47.98321	1
48.0027	1.145833
48.02218	1.25
48.04167	1
48.06116	1.145833
48.08065	1.385417
48.10014	1.5625
48.11963	1.416667
48.13912	1.59375
48.1586	1.96875
48.17809	2.041667
48.19758	2.739583
48.21707	3.197917
48.23656	3.354167
48.25605	3.645833
48.27554	3.15625
48.29502	3.520833
48.31451	3.510417
48.334	3.302083

48.35349	3.208333
48.37298	2.75
48.39247	2.854167
48.41196	2.541667
48.43144	2.40625
48.45093	2.302083
48.47042	2.03125
48.48991	1.885417
48.5094	1.895833
48.52889	1.739583
48.54838	1.260417
48.56786	1.479167
48.58735	1.052083
48.60684	1.083333
48.62633	1
48.64582	0.989583
48.66531	1.104167
48.6848	1.052083
48.70428	0.833333
48.72377	0.885417
48.74326	1.145833
48.76275	1.0625
48.78224	0.875
48.80173	0.916667
48.82122	1.020833
48.8407	1
48.86019	1.020833
48.87968	0.71875
48.89917	0.677083
48.91866	1
48.93815	0.666667
48.95764	0.90625
48.97712	0.791667
48.99661	0.635417
49.0161	0.604167
49.03559	0.666667
49.05508	0.635417
49.07457	0.635417
49.09406	0.729167
49.11354	0.520833
49.13303	0.614583
49.15252	0.770833
49.17201	0.729167
49.1915	0.833333
49.21099	0.635417
49.230475101620	0.875

49.24996	0.708333
49.26945	0.614583
49.28894	0.802083
49.30843	0.833333
49.32792	0.59375
49.34741	0.822917
49.3669	0.791667
49.38638	0.697917
49.40587	0.697917
49.42536	0.729167
49.44485	0.916667
49.46434	0.65625
49.48383	0.541667
49.50331	0.677083
49.5228	0.666667
49.54229	0.65625
49.56178	0.677083
49.58127	0.75
49.60076	0.729167
49.62025	0.802083
49.63973	0.625
49.65922	0.697917
49.67871	0.802083
49.6982	0.729167
49.71769	0.8125
49.73718	0.729167
49.75667	0.71875
49.77615	0.770833
49.79564	0.84375
49.81513	0.84375
49.83462	0.791667
49.85411	0.833333
49.8736	0.96875
49.89309	0.9375
49.91257	1
49.93206	1.114583
49.95155	1.0625
49.97104	1.03125
49.99053	0.75
50.01002	0.895833
50.02951	1.083333
50.04899	1.0625
50.06848	1.177083
50.08797	1.40625
50.10746	1.364583
50.12695	1.28125

50.14644	1.625
50.16593	2.125
50.18541	1.979167
50.2049	2.697917
50.22439	3
50.24388	3.458333
50.26337	4.510417
50.28286	5.302083
50.30235	5.875
50.32183	5.791667
50.34132	5.322917
50.36081	5.322917
50.3803	5.145833
50.39979	5.125
50.41928	4.791667
50.43877	4.09375
50.45825	4.114583
50.47774	3.083333
50.49723	2.71875
50.51672	2.302083
50.53621	2.21875
50.5557	1.875
50.57519	1.552083
50.59467	1.802083
50.61416	1.6875
50.63365	1.229167
50.65314	1.270833
50.67263	1.28125
50.69212	1.15625
50.71161	1.197917
50.73109	0.875
50.75058	0.90625
50.77007	1.03125
50.78956	1.0625
50.80905	0.8125
50.82854	1.020833
50.84803	0.96875
50.86751	0.947917
50.887	0.90625
50.90649	0.979167
50.92598	0.90625
50.94547	1.020833
50.96496	1.041667
50.98445	0.854167
51.00393	0.916667
51.02342	0.864583

51.04291	0.864583
51.0624	0.791667
51.08189	0.833333
51.10138	1.052083
51.12087	0.9375
51.14035416767 0	0.84375
51.15984	0.833333
51.17933	0.833333
51.19882	0.875
51.21831	0.78125
51.2378	0.979167
51.25729	0.916667
51.27677	0.979167
51.29626	0.739583
51.31575	0.65625
51.33524	0.666667
51.35473	0.84375
51.37422	0.739583
51.39371	0.635417
51.41319	0.65625
51.43268	0.625
51.45217	0.708333
51.47166	0.71875
51.49115	0.635417
51.51064	0.677083
51.53013	0.791667
51.54961	0.71875
51.5691	0.677083
51.58859	0.791667
51.60808	0.53125
51.62757	0.697917
51.64706	0.53125
51.66655	0.614583
51.68603	0.583333
51.70552	0.6875
51.72501	0.59375
51.7445	0.697917
51.76399	0.645833
51.78348	0.614583
51.80297	0.614583
51.82245	0.8125
51.84194	0.729167
51.86143	0.697917
51.88092	0.645833
51.90041	0.5625
51.9199	0.625

51.93939	0.552083
51.95887	0.645833
51.97836	0.708333
51.99785	0.677083
52.01734	0.739583
52.03683	0.614583
52.05632	0.677083
52.07581	0.75
52.09529	0.708333
52.11478	0.59375
52.13427	0.541667
52.15376	0.677083
52.17325	0.625
52.19274	0.697917
52.21223	0.916667
52.23171	0.885417
52.2512	0.791667
52.27069	0.59375
52.29018	0.71875
52.30967	0.520833
52.32916	0.71875
52.34865	0.614583
52.36813	0.770833
52.38762	0.635417
52.40711	0.75
52.4266	0.5625
52.44609	0.697917
52.46558	0.552083
52.48506	0.677083
52.50455	0.729167
52.52404	0.697917
52.54353	0.583333
52.56302	0.697917
52.58251	0.84375
52.602	0.635417
52.62148	0.75
52.64097	0.864583
52.66046	0.729167
52.67995	0.708333
52.69944	0.677083
52.71893	0.71875
52.73842	0.875
52.7579	0.78125
52.77739	0.864583
52.796881929040	0.84375
52.81637	0.739583

52.83586	0.916667
52.85535	0.708333
52.87484	0.770833
52.89432	0.958333
52.91381	0.916667
52.9333	0.822917
52.95279	0.854167
52.97228	0.895833
52.99177	0.947917
53.01126	0.864583
53.03074	0.84375
53.05023	1.041667
53.06972	1.145833
53.08921	0.96875
53.1087	1.208333
53.12819	1.208333
53.14768	1.177083
53.16716	1.052083
53.18665	1.270833
53.20614	1.135417
53.22563	1.229167
53.24512	1.197917
53.26461	1.53125
53.2841	1.322917
53.30358	1.625
53.32307	1.46875
53.34256	1.979167
53.36205	1.833333
53.38154	1.791667
53.40103	1.760417
53.42052	2.145833
53.44	1.885417
53.45949	2.083333
53.47898	2.53125
53.49847	2.71875
53.51796	2.46875
53.53745	2.572917
53.55694	2.989583
53.57642	3.020833
53.59591	3.354167
53.6154	3.583333
53.63489	4.145833
53.65438	3.885417
53.67387	4.166667
53.69336	5
53.71284	5.625

53.73233	7.03125
53.75182	8.927083
53.77131	10.75
53.7908	13.05208
53.81029	13.96875
53.82978	15.9375
53.84926	15.19792
53.86875	13.82292
53.88824	13.07292
53.90773	13.25
53.92722	11.85417
53.94671	12.70833
53.9662	11.35417
53.98568	9.53125
54.00517	8.375
54.02466	7.541667
54.04415	5.989583
54.06364	5.572917
54.08313	4.416667
54.10262	4.385417
54.1221	3.59375
54.14159	3.520833
54.16108	3.291667
54.18057	3.0625
54.20006	2.53125
54.21955	2.53125
54.23904	2.25
54.25852	2.458333
54.27801	2.15625
54.2975	1.90625
54.31699	1.875
54.33648	1.677083
54.35597	1.65625
54.37546	1.583333
54.39494	1.5625
54.41443	1.5625
54.43392	1.34375
54.45341	1.28125
54.4729	1.302083
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54.51188	1.291667
54.53136	0.989583
54.55085	1.072917
54.57034	1.177083
54.58983	1.166667
54.60932	1.0625

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54.6483	1.166667
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54.68727	1.177083
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54.72625	0.833333
54.74574	0.979167
54.76523	0.916667
54.78472	1.0625
54.8042	0.927083
54.82369	0.947917
54.84318	1.09375
54.86267	0.822917
54.88216	0.979167
54.90165	0.697917
54.92114	0.916667
54.94062	1.083333
54.96011	0.729167
54.9796	0.791667
54.99909	0.9375
55.01858	0.791667
55.03807	0.791667
55.05756	0.885417
55.07704	0.864583
55.09653	0.864583
55.11602	0.677083
55.13551	0.760417
55.155	0.885417
55.17449	0.864583
55.19398	0.916667
55.21346	0.84375
55.23295	0.90625
55.25244	0.854167
55.27193	0.802083
55.29142	0.947917
55.31091	0.84375
55.33039	0.864583
55.34988	0.864583
55.36937	1.041667
55.38886	1.0625
55.40835	0.9375
55.42784	1.114583
55.44733	1.010417
55.46681	0.916667
55.4863	1.052083
55.50579	1

55.52528	0.916667
55.54477	1.020833
55.56426	1.114583
55.58375	0.760417
55.60323	0.875
55.62272	0.916667
55.64221	0.895833
55.6617	1.020833
55.68119	1.041667
55.70068	0.885417
55.72017	1.114583
55.73965	1.020833
55.75914	0.895833
55.77863	0.864583
55.79812	0.8125
55.81761	0.989583
55.8371	1.03125
55.85659	1.020833
55.87607	1.125
55.89556	1.229167
55.91505	0.927083
55.93454	1.208333
55.95403	0.916667
55.97352	1.114583
55.99301	0.875
56.01249	1.072917
56.03198	1.09375
56.05147	1.197917
56.07096	1.15625
56.09045	1.260417
56.10994	1.270833
56.12943	0.895833
56.14891	1.135417
56.1684	1.28125
56.18789	1.09375
56.20738	1.28125
56.22687	1.083333
56.24636	1.09375
56.26585	1.135417
56.28533	1.135417
56.30482	1.135417
56.32431	1.520833
56.3438	1.15625
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56.38278	1.4375
56.40227	1.447917

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56.44124	1.333333
56.46073	1.541667
56.48022	1.635417
56.49971	1.479167
56.5192	2.229167
56.53869	1.895833
56.55817	2.208333
56.57766	2.072917
56.59715	1.979167
56.61664	2.4375
56.63613	2.395833
56.65562	2.958333
56.67511	2.927083
56.69459	3.583333
56.71408	3.75
56.73357	4.510417
56.75306	5.958333
56.77255	6.4375
56.79204	6.666667
56.81153	7.072917
56.83101	7.4375
56.8505	7.239583
56.86999	6.895833
56.88948	7.75
56.90897	7.979167
56.92846	7.6875
56.94795	7.510417
56.96743	7.041667
56.98692	6.770833
57.00641	5.90625
57.0259	5.78125
57.04539	5.270833
57.06488	5.083333
57.08437	4.083333
57.10385	3.854167
57.12334	3.5625
57.14283	3.208333
57.16232	3.270833
57.18181	2.364583
57.2013	2.489583
57.22079	2.166667
57.24027	2.229167
57.25976	1.979167
57.27925	1.84375
57.29874	1.395833

57.31823	1.84375
57.33772	1.677083
57.35721	1.427083
57.37669	1.541667
57.39618	1.354167
57.41567	1.197917
57.43516	1.3125
57.45465	1.40625
57.47414	1.239583
57.49363	1.229167
57.51311	1.260417
57.5326	1.1875
57.55209	1.104167
57.57158	1.010417
57.59107	1.135417
57.61056	0.958333
57.63005	0.864583
57.64953	1
57.66902	0.84375
57.68851	0.96875
57.708	0.958333
57.72749	0.84375
57.74698	0.770833
57.76647	0.885417
57.78595	0.770833
57.80544	0.8125
57.82493	0.78125
57.84442	0.947917
57.86391	0.96875
57.8834	0.833333
57.90289	0.875
57.92237	0.739583
57.94186	0.78125
57.96135	0.875
57.98084	0.802083
58.00033	0.947917
58.01982	0.9375
58.03931	0.885417
58.05879	0.96875
58.07828	0.770833
58.09777	0.822917
58.11726	1.072917
58.13675	0.947917
58.15624	0.78125
58.17573	1.052083
58.19521	0.75

58.2147	0.833333
58.23419	0.78125
58.25368	0.677083
58.273167822510	0.90625
58.29266	0.958333
58.31214	0.822917
58.33163	0.84375
58.35112	0.760417
58.37061	1.010417
58.3901	0.9375
58.40959	0.916667
58.42908	0.8125
58.44856	0.90625
58.46805	0.96875
58.48754	0.84375
58.50703	1.125
58.52652	0.958333
58.54601	1.083333
58.5655	0.90625
58.58498	1.229167
58.60447	1.3125
58.62396	1.479167
58.64345	1.34375
58.66294	1.59375
58.68243	1.166667
58.70192	1.375
58.7214	1.541667
58.74089	1.364583
58.76038	1.427083
58.77987	1.385417
58.79936	1.5
58.81885	1.8125
58.83834	1.645833
58.85782	1.760417
58.87731	1.833333
58.8968	1.822917
58.91629	1.895833
58.93578	2.177083
58.95527	2.25
58.97476	2.5625
58.99424	3
59.01373	3.479167
59.03322	3.864583
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59.13066	4.9375
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59.16964	5.322917
59.18913	4.875
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59.22811	4.9375
59.2476	4.25
59.26708	3.979167
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59.30606	2.96875
59.32555	2.822917
59.34504	2.5
59.36453	2.28125
59.38402	2.125
59.4035	1.8125
59.42299	1.71875
59.44248	1.46875
59.46197	1.479167
59.48146	1.197917
59.50095	1.395833
59.52044	1.239583
59.53992	1.072917
59.55941	1.1875
59.5789	1.09375
59.59839	1.177083
59.61788	1.177083
59.63737	0.895833
59.65686	1.114583
59.67634	0.947917
59.69583	0.770833
59.71532	0.885417
59.73481	0.75
59.7543	0.822917
59.77379	0.84375
59.79328	0.802083
59.81276	0.75
59.83225	0.802083
59.85174	0.895833
59.87123	0.927083
59.89072	0.635417
59.91021	0.71875
59.9297	0.760417
59.94918	0.625
59.96867	0.708333
59.98816	0.71875

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60.02714	0.552083
60.04663	0.65625
60.06612	0.8125
60.0856	0.65625
60.10509	0.604167
60.12458	0.65625
60.14407	0.5
60.16356	0.59375
60.18305	0.635417
60.20254	0.59375
60.22202	0.572917
60.24151	0.75
60.261	0.541667
60.28049	0.729167
60.29998	0.708333
60.31947	0.5625
60.33896	0.729167
60.35844	0.791667
60.37793	0.46875
60.39742	0.666667
60.41691	0.645833
60.4364	0.59375
60.45589	0.583333
60.47538	0.697917
60.49486	0.625
60.51435	0.489583
60.53384	0.583333
60.55333	0.677083
60.57282	0.697917
60.59231	0.6875
60.6118	0.59375
60.63128	0.6875
60.65077	0.78125
60.67026	0.708333
60.68975	0.697917
60.70924	0.708333
60.72873	0.5625
60.74822	0.604167
60.7677	0.666667
60.78719	0.729167
60.80668	0.760417
60.82617	0.760417
60.84566	0.71875
60.86515	0.75
60.88464	0.729167

60.90412	0.78125
60.92361	0.739583
60.9431	0.697917
60.96259	0.71875
60.98208	0.9375
61.00157	0.9375
61.02106	0.854167
61.04054	0.9375
61.06003	1.020833
61.07952	0.958333
61.09901	1.0625
61.1185	1.260417
61.13799	1.208333
61.15747	1.479167
61.17696	1.354167
61.19645	1.28125
61.21594	1.072917
61.23543	1.322917
61.25492	1.09375
61.27441	1.260417
61.29389	1.25
61.31338	1.260417
61.33287	1.322917
61.35236	1.052083
61.37185	1.239583
61.39134	1.28125
61.41083	1.322917
61.43031	1.177083
61.4498	1.229167
61.46929	1.229167
61.48878	1.239583
61.50827	1.375
61.52776	1.520833
61.54725	1.729167
61.56673	1.708333
61.58622	1.770833
61.60571	2.072917
61.6252	2.208333
61.64469	2.447917
61.66418	2.5
61.68367	2.895833
61.70315	3.375
61.72264	4
61.74213	4.979167
61.76162	5.208333
61.78111	5.197917

61.8006	5.666667
61.82009	5.166667
61.839574649934	0.739583
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61.87855	4.770833
61.89804	4.520833
61.91753	4.333333
61.93702	4.229167
61.95651	4.260417
61.97599	3.229167
61.99548	3.447917
62.01497	2.895833
62.03446	2.4375
62.05395	2.8125
62.07344	2.5625
62.09293	2.229167
62.11241	2.333333
62.1319	1.791667
62.15139	1.864583
62.17088	2
62.19037	2.177083
62.20986	2
62.22935	1.791667
62.24883	2.208333
62.26832	2.395833
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62.3073	2.59375
62.32679	2.895833
62.34628	2.979167
62.36577	3.25
62.38525	3.135417
62.40474	3.385417
62.42423	3.427083
62.44372	4.010417
62.46321	4.364583
62.4827	3.895833
62.50219	3.9375
62.52167	3.885417
62.54116	3.260417
62.56065	3.21875
62.58014	3.104167
62.59963	3.072917
62.61912	3.010417
62.63861	2.479167
62.65809	2.572917
62.67758	2.145833

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62.71656	1.90625
62.73605	1.364583
62.75554	1.489583
62.77503	1.375
62.79451	1.28125
62.814	1.197917
62.83349	1.114583
62.85298	1.125
62.87247	0.979167
62.89196	1.125
62.91145	0.875
62.93093	0.916667
62.95042	0.854167
62.96991	0.9375
62.9894	0.822917
63.00889	0.729167
63.02838	0.927083
63.04787	0.864583
63.06735	0.604167
63.08684	0.75
63.10633	0.958333
63.12582	0.625
63.14531	0.697917
63.1648	0.791667
63.18429	0.666667
63.20377	0.75
63.22326	0.895833
63.24275	0.802083
63.26224	0.541667
63.28173	0.739583
63.30122	0.75
63.32071	0.697917
63.34019	0.552083
63.35968	0.802083
63.37917	0.645833
63.39866	0.65625
63.41815	0.864583
63.43764	0.53125
63.45713	0.833333
63.47661	0.5625
63.4961	0.697917
63.51559	0.71875
63.53508	0.770833
63.55457	0.947917
63.57406	0.791667

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63.61303	0.885417
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63.65201	0.989583
63.6715	0.947917
63.69099	0.885417
63.71048	0.947917
63.72997	0.71875
63.74945	0.78125
63.76894	0.864583
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63.80792	0.645833
63.82741	0.739583
63.8469	0.78125
63.86639	0.604167
63.88587	0.697917
63.90536	0.71875
63.92485	0.510417
63.94434	0.59375
63.96383	0.583333
63.98332	0.677083
64.00281	0.625
64.02229	0.583333
64.04178	0.604167
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64.11974	0.4375
64.13922	0.510417
64.15871	0.510417
64.1782	0.5
64.19769	0.489583
64.21718	0.510417
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64.25616	0.645833
64.27564	0.677083
64.29513	0.583333
64.31462	0.59375
64.33411	0.5625
64.3536	0.46875
64.37309	0.489583
64.39258	0.6875
64.41206	0.427083
64.43155	0.447917
64.45104	0.572917
64.47053	0.583333

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64.529	0.635417
64.54848	0.53125
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64.58746	0.46875
64.60695	0.510417
64.62644	0.395833
64.64593	0.40625
64.66542	0.479167
64.6849	0.4375
64.70439	0.479167
64.72388	0.510417
64.74337	0.59375
64.76286	0.458333
64.78235	0.552083
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64.82132	0.489583
64.84081	0.59375
64.8603	0.53125
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64.95774	0.458333
64.97723	0.572917
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65.13314	0.489583
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65.23058	0.510417
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65.367	0.4375

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65.69831	0.572917
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65.73729	0.458333
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65.79575	0.604167
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65.83473	0.520833
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65.91268	0.5
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65.95166	0.541667
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66.10757	0.645833
66.12706	0.697917
66.14655	0.739583
66.16604	0.583333
66.18552	0.635417
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66.24399	0.75
66.26348	0.75

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66.34143	0.96875
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66.3999	0.802083
66.41939	0.96875
66.43888	0.833333
66.45836	0.822917
66.47785	0.947917
66.49734	0.833333
66.51683	0.833333
66.53632	0.875
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66.5753	0.71875
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66.61427	0.71875
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66.65325	0.65625
66.67274	0.770833
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66.88711	0.666667
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67.082	0.927083
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67.15995	0.979167

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67.39381	0.614583
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67.43279	0.6875
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67.54972	0.53125
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67.68614	0.4375
67.70563	0.572917
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67.80307	0.552083
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67.84205	0.53125
67.86154	0.5625
67.88103	0.447917
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67.93949	0.5625
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68.05643	0.614583

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68.0954	0.604167
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68.13438	0.552083
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68.17336	0.65625
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68.2708	0.552083
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68.52415	0.385417
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68.58262	0.46875
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68.71904	0.510417
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68.7775	0.53125
68.79699	0.65625
68.81648	0.4375
68.83597	0.541667
68.85546	0.364583
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68.9529	0.4375

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69.05034	0.614583
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69.08932	0.479167
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69.1283	0.59375
69.14779	0.447917
69.16727	0.447917
69.18676	0.46875
69.20625	0.510417
69.22574	0.65625
69.24523	0.510417
69.26472	0.604167
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69.55705	0.520833
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69.61551	0.59375
69.635	0.552083
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69.67398	0.708333
69.69347	0.635417
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69.9663	0.958333
69.98579	1.1875
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70.1417	1.541667
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70.21966	1.25
70.23914	1.1875
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70.43403	1.03125
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70.55096	0.770833
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70.66789	0.708333
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74.19532	0.614583
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75.44259	1.145833
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75.55952	0.875
75.57901	0.9375
75.5985	0.78125
75.61799	0.875
75.63748	0.6875
75.65697	0.885417
75.67645	0.833333
75.69594	0.760417
75.71543	0.729167
75.73492	0.760417
75.75441	0.625
75.7739	0.645833
75.79338	0.6875
75.81287	0.729167
75.83236	0.604167
75.85185	0.71875
75.87134	0.59375
75.89083	0.84375
75.91032	0.604167
75.9298	0.677083
75.94929	0.65625
75.96878	0.666667
75.98827	0.489583
76.00776	0.520833
76.02725	0.666667
76.04674	0.583333
76.06622	0.708333
76.08571	0.625
76.105201959610	0.510417
76.12469	0.583333

76.14418	0.65625
76.16367	0.6875
76.18316	0.520833
76.20264	0.635417
76.22213	0.635417
76.24162	0.5
76.26111	0.5
76.2806	0.635417
76.30009	0.65625
76.31958	0.708333
76.33906	0.666667
76.35855	0.625
76.37804	0.604167
76.39753	0.458333
76.41702	0.645833
76.43651	0.65625
76.456	0.59375
76.47548	0.708333
76.49497	0.614583
76.51446	0.53125
76.53395	0.552083
76.55344	0.552083
76.57293	0.479167
76.59242	0.520833
76.6119	0.583333
76.63139	0.572917
76.65088	0.510417
76.67037	0.583333
76.68986	0.510417
76.70935	0.458333
76.72884	0.614583
76.74832	0.677083
76.76781	0.572917
76.7873	0.697917
76.80679	0.53125
76.82628	0.625
76.84577	0.677083
76.86526	0.59375
76.88474	0.59375
76.90423	0.59375
76.92372	0.770833
76.94321	0.677083
76.9627	0.791667
76.98219	0.635417
77.00168	0.666667
77.02116	0.645833

77.04065	0.697917
77.06014	0.489583
77.07963	0.614583
77.09912	0.708333
77.11861	0.604167
77.1381	0.708333
77.15758	0.541667
77.17707	0.614583
77.19656	0.822917
77.21605	0.6875
77.23554	0.71875
77.25503	0.635417
77.27452	0.666667
77.294	0.729167
77.31349	0.572917
77.33298	0.5
77.35247	0.635417
77.37196	0.604167
77.39145	0.541667
77.41094	0.6875
77.43042	0.53125
77.44991	0.666667
77.4694	0.59375
77.48889	0.729167
77.50838	0.489583
77.52787	0.739583
77.54736	0.729167
77.56684	0.520833
77.58633	0.458333
77.60582	0.458333
77.62531	0.53125
77.6448	0.635417
77.66429	0.625
77.68378	0.541667
77.70326	0.59375
77.72275	0.541667
77.74224	0.520833
77.76173	0.625
77.78122	0.625
77.80071	0.604167
77.8202	0.489583
77.83968	0.5
77.85917	0.583333
77.87866	0.458333
77.89815	0.6875
77.91764	0.604167

77.93713	0.541667
77.95662	0.59375
77.9761	0.5625
77.99559	0.583333
78.015081025660	0.5625
78.03457	0.677083
78.05406	0.5625
78.07355	0.572917
78.09304	0.677083
78.11252	0.5625
78.13201	0.78125
78.1515	0.6875
78.17099	0.635417
78.19048	0.645833
78.20997	0.625
78.22946	0.666667
78.24894	0.583333
78.26843	0.760417
78.28792	0.791667
78.30741	0.8125
78.3269	0.885417
78.34639	0.84375
78.36588	0.729167
78.38536	0.875
78.40485	0.885417
78.42434	1
78.44383	0.989583
78.46332	1.0625
78.48281	0.833333
78.5023	1.020833
78.52178	1.270833
78.54127	1.208333
78.56076	1.385417
78.58025	1.09375
78.59974	1.375
78.61923	1.0625
78.63872	1.34375
78.6582	1.197917
78.67769	1.34375
78.69718	1.416667
78.71667	1.4375
78.73616	1.354167
78.75565	1.46875
78.77513	1.395833
78.79462	1.114583
78.81411	1.020833

78.8336	1.135417
78.85309	1.333333
78.87258	1.15625
78.89207	1.125
78.91155	1.166667
78.93104	1.1875
78.95053	1.104167
78.97002	0.927083
78.98951	1.21875
79.009	0.822917
79.02849	1.03125
79.04797	0.989583
79.06746	1.083333
79.08695	1.010417
79.10644	0.854167
79.12593	1.208333
79.14542	1.114583
79.16491	1.197917
79.18439	1.3125
79.20388	1.302083
79.22337	1.322917
79.24286	1.145833
79.26235	1.177083
79.28184	1.104167
79.30133	1.072917
79.32081	1.135417
79.3403	1.145833
79.35979	1.083333
79.37928	1.166667
79.39877	1.020833
79.41826	1.145833
79.43775	0.958333
79.45723	0.770833
79.47672	0.989583
79.49621	0.864583
79.5157	0.739583
79.53519	0.739583
79.55468	0.802083
79.57417	0.635417
79.59365	0.729167
79.61314	0.677083
79.63263	0.614583
79.65212	0.572917
79.671608787030	0.583333
79.6911	0.729167
79.71059	0.635417

79.73007	0.447917
79.74956	0.5625
79.76905	0.604167
79.78854	0.5625
79.80803	0.635417
79.82752	0.59375
79.84701	0.625
79.86649	0.604167
79.88598	0.6875
79.90547	0.489583
79.92496	0.427083
79.94445	0.541667
79.96394	0.520833
79.98343	0.59375
80.00291	0.645833
80.0224	0.604167
80.04189	0.4375
80.06138	0.552083
80.08087	0.604167
80.10036	0.479167
80.11985	0.5625
80.13933	0.520833
80.15882	0.427083
80.17831	0.5625
80.1978	0.604167
80.21729	0.40625
80.23678	0.552083
80.25627	0.46875
80.27575	0.5
80.29524	0.572917
80.31473	0.614583
80.33422	0.53125
80.35371	0.614583
80.3732	0.572917
80.39269	0.4375
80.41217	0.53125
80.43166	0.677083
80.45115	0.510417
80.47064	0.510417
80.49013	0.572917
80.50962	0.5625
80.52911	0.583333
80.54859	0.583333
80.56808	0.458333
80.58757	0.479167
80.60706	0.604167

80.62655	0.489583
80.64604	0.59375
80.66553	0.520833
80.68501	0.625
80.7045	0.458333
80.72399	0.541667
80.74348	0.458333
80.76297	0.552083
80.78246	0.59375
80.80195	0.510417
80.82143	0.635417
80.84092	0.59375
80.86041	0.489583
80.8799	0.625
80.89939	0.364583
80.91888	0.541667
80.93837	0.552083
80.95785	0.479167
80.97734	0.625
80.99683	0.53125
81.01632	0.541667
81.03581	0.666667
81.0553	0.65625
81.07479	0.677083
81.09427	0.614583
81.11376	0.583333
81.13325	0.604167
81.15274	0.541667
81.17223	0.583333
81.19172	0.5625
81.21121	0.552083
81.23069	0.71875
81.25018	0.645833
81.26967	0.645833
81.28916	0.479167
81.30865	0.71875
81.32814	0.572917
81.34763	0.739583
81.36711	0.614583
81.3866	0.510417
81.40609	0.583333
81.42558	0.625
81.44507	0.614583
81.46456	0.572917
81.48405	0.604167
81.50353	0.604167

81.52302	0.65625
81.54251	0.552083
81.562	0.677083
81.581487853080	0.75
81.60098	0.75
81.62046	0.770833
81.63995	0.802083
81.65944	0.833333
81.67893	0.645833
81.69842	0.916667
81.71791	0.802083
81.7374	0.90625
81.75688	0.9375
81.77637	0.916667
81.79586	0.927083
81.81535	1.114583
81.83484	1.072917
81.85433	1.197917
81.87382	1.09375
81.8933	1.1875
81.91279	1.177083
81.93228	1.125
81.95177	1.166667
81.97126	1.041667
81.99075	1.010417
82.01024	1.427083
82.02972	1.114583
82.04921	0.802083
82.0687	1
82.08819	1.145833
82.10768	1.09375
82.12717	0.947917
82.14666	1.114583
82.16614	1.041667
82.18563	0.927083
82.20512	0.958333
82.22461	1.125
82.2441	1.166667
82.26359	1.229167
82.28308	1.114583
82.30256	1.4375
82.32205	1.354167
82.34154	1.270833
82.36103	1.416667
82.38052	1.302083
82.40001	1.1875

82.4195	1.21875
82.43898	1.03125
82.45847	1.041667
82.47796	1.1875
82.49745	1.166667
82.51694	1.09375
82.53643	0.947917
82.55592	0.979167
82.5754	1.09375
82.59489	0.833333
82.61438	1.052083
82.63387	0.802083
82.65336	0.927083
82.67285	0.958333
82.69234	0.895833
82.71182	0.989583
82.73131	0.885417
82.7508	0.958333
82.77029	0.802083
82.78978	0.739583
82.80927	0.666667
82.82876	0.927083
82.84824	0.927083
82.86773	0.760417
82.88722	0.84375
82.90671	0.90625
82.9262	0.96875
82.94569	0.989583
82.96518	0.96875
82.98466	0.989583
83.00415	0.854167
83.02364	0.791667
83.04313	0.958333
83.06262	0.96875
83.08211	0.822917
83.1016	0.979167
83.12108	0.833333
83.14057	0.760417
83.16006	0.864583
83.17955	0.958333
83.19904	0.895833
83.21853	0.614583
83.238015614450	0.770833
83.2575	0.854167
83.27699	0.71875
83.29648	0.8125

83.31597	0.697917
83.33546	0.697917
83.35495	0.6875
83.37444	0.6875
83.39392	0.6875
83.41341	0.6875
83.4329	0.614583
83.45239	0.572917
83.47188	0.489583
83.49137	0.8125
83.51086	0.5
83.53034	0.677083
83.54983	0.645833
83.56932	0.854167
83.58881	0.916667
83.6083	0.791667
83.62779	0.770833
83.64728	0.916667
83.66676	0.802083
83.68625	1.041667
83.70574	0.895833
83.72523	0.895833
83.74472	0.916667
83.76421	0.927083
83.7837	0.802083
83.80318	0.677083
83.82267	0.9375
83.84216	0.729167
83.86165	0.90625
83.88114	0.65625
83.90063	0.8125
83.92012	0.8125
83.9396	0.8125
83.95909	0.677083
83.97858	0.625
83.99807	0.71875
84.01756	0.645833
84.03705	0.6875
84.05654	0.645833
84.07602	0.78125
84.09551	0.625
84.115	0.604167
84.13449	0.697917
84.15398	0.65625
84.17347	0.625
84.19296	0.53125

84.21244	0.614583
84.23193	0.604167
84.25142	0.65625
84.27091	0.541667
84.2904	0.666667
84.30989	0.697917
84.32938	0.5625
84.34886	0.46875
84.36835	0.65625
84.38784	0.697917
84.40733	0.5625
84.42682	0.5625
84.44631	0.6875
84.4658	0.447917
84.48528	0.9375
84.50477	0.677083
84.52426	0.552083
84.54375	0.541667
84.56324	0.697917
84.58273	0.833333
84.60221	0.677083
84.6217	0.802083
84.64119	0.71875
84.66068	0.760417
84.68017	0.822917
84.69966	0.770833
84.71915	0.822917
84.73863	0.75
84.75812	0.822917
84.77761	0.958333
84.7971	0.791667
84.81659	0.791667
84.83608	0.833333
84.85557	0.760417
84.87505	0.729167
84.89454	0.604167
84.91403	0.635417
84.93352	0.729167
84.95301	0.666667
84.9725	0.645833
84.99199	0.802083
85.01147	0.708333
85.03096	0.677083
85.05045	0.489583
85.06994	0.666667
85.08943	0.625

85.10892	0.510417
85.12841	0.635417
85.1478946805 0.	5.73E+14
85.16738	0.604167
85.18687	0.666667
85.20636	0.635417
85.22585	0.604167
85.24534	0.59375
85.26483	0.59375
85.28431	0.697917
85.3038	0.614583
85.32329	0.65625
85.34278	0.53125
85.36227	0.510417
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85.40125	0.5625
85.42073	0.479167
85.44022	0.583333
85.45971	0.4375
85.4792	0.479167
85.49869	0.46875
85.51818	0.46875
85.53767	0.59375
85.55715	0.354167
85.57664	0.395833
85.59613	0.541667
85.61562	0.510417
85.63511	0.59375
85.6546	0.458333
85.67409	0.5625
85.69357	0.510417
85.71306	0.447917
85.73255	0.416667
85.75204	0.447917
85.77153	0.59375
85.79102	0.479167
85.81051	0.489583
85.82999	0.5
85.84948	0.458333
85.86897	0.395833
85.88846	0.625
85.90795	0.583333
85.92744	0.479167
85.94693	0.53125
85.96641	0.59375
85.9859	0.510417

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86.02488	0.583333
86.04437	0.65625
86.06386	0.510417
86.08335	0.59375
86.10283	0.53125
86.12232	0.53125
86.14181	0.510417
86.1613	0.427083
86.18079	0.489583
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86.21977	0.5625
86.23925	0.552083
86.25874	0.458333
86.27823	0.53125
86.29772	0.479167
86.31721	0.447917
86.3367	0.510417
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86.41465	0.479167
86.43414	0.614583
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86.668	0.729167
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86.74596	0.645833
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86.78493	0.666667
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86.86289	0.739583
86.88238	0.572917

86.90187	0.635417
86.92135	0.5625
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86.96033	0.552083
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86.99931	0.520833
87.0188	0.5625
87.03829	0.625
87.05777	0.625
87.07726	0.541667
87.09675	0.489583
87.11624	0.447917
87.13573	0.583333
87.15522	0.541667
87.17471	0.552083
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87.21368	0.489583
87.23317	0.5
87.25266	0.458333
87.27215	0.489583
87.29164	0.53125
87.31113	0.520833
87.33061	0.583333
87.3501	0.479167
87.36959	0.354167
87.38908	0.552083
87.40857	0.520833
87.42806	0.447917
87.44754	0.510417
87.46703	0.46875
87.48652	0.489583
87.50601	0.489583
87.5255	0.447917
87.54499	0.489583
87.56448	0.552083
87.58396	0.59375
87.60345	0.635417
87.62294	0.489583
87.64243	0.614583
87.66192	0.458333
87.68141	0.53125
87.7009	0.572917
87.72038	0.479167
87.73987	0.541667
87.75936	0.53125
87.77885	0.510417

87.79834	0.635417
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87.83732	0.447917
87.8568	0.4375
87.87629	0.5625
87.89578	0.635417
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87.93476	0.4375
87.95425	0.458333
87.97374	0.489583
87.99322	0.604167
88.01271	0.510417
88.0322	0.416667
88.05169	0.677083
88.07118	0.604167
88.09067	0.583333
88.11016	0.583333
88.12964	0.604167
88.14913	0.447917
88.16862	0.53125
88.18811	0.458333
88.2076	0.541667
88.22709	0.708333
88.24658	0.65625
88.26606	0.489583
88.28555	0.614583
88.30504	0.5
88.32453	0.458333
88.34402	0.510417
88.36351	0.572917
88.383	0.510417
88.40248	0.395833
88.42197	0.520833
88.44146	0.541667
88.46095	0.46875
88.48044	0.458333
88.49993	0.458333
88.51942	0.427083
88.5389	0.520833
88.55839	0.447917
88.57788	0.541667
88.59737	0.552083
88.61686	0.59375
88.63635	0.625
88.65584	0.5625
88.67532	0.4375

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88.73379	0.583333
88.75328	0.583333
88.77277	0.552083
88.79226	0.583333
88.81174	0.53125
88.83123	0.541667
88.85072	0.572917
88.87021	0.510417
88.8897	0.520833
88.90919	0.583333
88.92868	0.552083
88.94816	0.583333
88.96765	0.416667
88.98714	0.447917
89.00663	0.447917
89.02612	0.489583
89.04561	0.510417
89.0651	0.489583
89.08458	0.458333
89.10407	0.59375
89.12356	0.645833
89.14305	0.59375
89.16254	0.583333
89.18203	0.4375
89.20152	0.510417
89.221	0.46875
89.24049	0.489583
89.25998	0.46875
89.27947	0.46875
89.29896	0.614583
89.31845	0.458333
89.33794	0.4375
89.35742	0.645833
89.37691	0.541667
89.3964	0.489583
89.41589	0.520833
89.43538	0.489583
89.45487	0.614583
89.47436	0.5625
89.49384	0.520833
89.51333	0.625
89.53282	0.447917
89.55231	0.572917
89.5718	0.572917

89.59129	0.416667
89.61078	0.479167
89.63026	0.572917
89.64975	0.572917
89.66924	0.572917
89.68873	0.59375
89.70822	0.666667
89.72771	0.5
89.7472	0.6875
89.76668	0.5625
89.78617	0.4375
89.80566	0.552083
89.82515	0.489583
89.84464	0.65625
89.86413	0.71875
89.88362	0.697917
89.9031	0.645833
89.92259	0.572917
89.94208	0.635417
89.96157	0.760417
89.98106	0.708333
90.00055	0.65625