Framing Australian Pleistocene Coastal Occupation and Archaeology

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Abstract

There are few archaeological sites that contain records for Pleistocene coastal occupation in Australia, as is the case globally. Two major viewpoints seek to explain why so few sites exist. The first is that the Pleistocene coast was a relatively marginal environment where fluctuating sea levels actively inhibited coastal resource productivity until the mid-to-late Holocene. The second position suggests that the Pleistocene coast (and its resources) was variably productive, potentially hosting extensive populations, but that the archaeological evidence for this occupation has been submerged by sea level rise. To help reconcile these perspectives in Australia, this paper provides a review, discussion, and assessment of the evidence for

Australian Pleistocene coastal productivity and occupation. In doing so, we find no reason to categorically assume that coastal landscapes were ever unproductive or unoccupied. We demonstrate that the majority of Pleistocene coastal archaeology will be drowned where dense marine faunal assemblages should only be expected close to palaeo-shorelines. Mixed terrestrial and marine assemblages are likely to occur at sites located >2km from Pleistocene shorelines. Ultimately, the discussions and arguments put forward in this paper provide a basic framework, and a different set of environmental expectations, within which to assess the results of independent coastal research.

Keywords: Pleistocene, coastal archaeology, Australia, sea levels

1 Introduction

Relatively little is known about occupation of Pleistocene coastal landscapes in Australia. This is partly because, compared to terrestrial Pleistocene records, there are few archaeological sites that contain records for Pleistocene coastal occupation. There are two major viewpoints that explain why so few sites contain records for Pleistocene coastal occupation around the world. The first is that the Pleistocene coast was a relatively marginal environment where fluctuating sea levels actively inhibited coastal resource productivity (e.g. Beaton, 1985; Cohen, 1977; Mulvaney and Kamminga, 1999; O'Connell et al., 2012; Osborn, 1977; Yesner, 1987; see Bicho and Hawes, 2008:2166-2167 and Erlandson, 2001 for summaries). According to this perspective it was only late in human history, under relative mid-to-late Holocene sea-level stabilisation, that humankind began to intensively exploit coastal resources, producing a 'coastal adaptation'. The second position argues that the Pleistocene coast (and its resources), was variably productive and critically important in facilitating both the evolution and dispersal of humankind (Bailey et al., 2007, 2015; Erlandson, 2001; Erlandson and Braje, 2015; Erlandson et al., 2007, 2015; Kyriacou et al., 2014; Marean, 2014; Parkington, 2010; Ward et al., 2015; Will et al. 2016). According to this position, rising post-glacial seas drowned most Pleistocene evidence for coastal occupation creating a preservation bias towards mid-to-late Holocene coastal archaeology (e.g. Bailey and Milner, 2002; Bailey and Flemming, 2008; Bicho and Hawes, 2008; Bicho et al., 2011; Erlandson, 2001; Erlandson and Fitzpatrick, 2006). Nevertheless, regardless of which argument is privileged, the problem still remains: we know very little about how people occupied and used now-drowned Pleistocene coasts and coastal landscapes.

The coastal archaeological record in Australia is, like many areas of the world, dominated by a mid-to-late Holocene coastal archaeology (e.g. Rowland et al., 2015; Ulm, 2011), although there was some recognition for the early use of coasts (e.g. Bowdler, 1977, 1990; Dortch, 1997; Morse, 1993a; White and O'Connell, 1982). The lack of Pleistocene evidence has been interpreted in light of the first viewpoint mentioned above: coasts were relatively unproductive due to fluctuating sea levels and only become economically important for Aboriginal hunter-gatherers from the mid-Holocene when stabilised sea levels resulted in widespread coastal productivity (e.g. Beaton, 1995; Hiscock, 2015; Nunn, 2020; Mulvaney and Kamminga, 1999; O'Connell and Allen, 2012; Pope and Terrell, 2007). While some evidence, particularly from the coastal northwest and New Ireland has challenged this view (e.g. Allen et al. 1989; Morse, 1999; Veth et al., 2007, 2017c; Ward et al., 2015), Pleistocene coastal archaeology is rare throughout the continent. This ultimately leaves two perspectives which seek to explain the relative lack of Australian Pleistocene coastal archaeology and so generates two important related questions. First, were Australian Pleistocene coasts productive landscapes? Second, did people widely occupy the varied Pleistocene coastal landscapes throughout Australia?

To help answer these questions, this paper reviews, discusses and assesses the evidence for Australian Pleistocene coastal productivity and occupation, including evidence from the wider Sahul region. However, these are difficult questions to answer because almost all relevant landscapes are now underwater. The available archaeological record on islands, archipelagos and areas adjacent to steep continental shelves represent the most tangible links to drowned coasts and so are the primary datasets that have been used to reconstruct the interaction of people with Australian Pleistocene coasts. In the first part of this paper, we review this archaeological literature to outline the current state of knowledge on Australian Pleistocene coastal archaeology. This review will outline the current standing of the Australian coastal literature and form a baseline to begin answering the two questions posed above. Drawing on international and palaeoenvironmental literature, in the second part of the paper we assess Australian Pleistocene coastal productivity and the likelihood of coastal occupation. This discussion provides a framework within which research questions and agendas can be better situated to study Pleistocene coastal occupation in Australia. Based on this framework, we identify major directions for future research on Pleistocene coastal landscapes.

2 Defining the Coast and its Resources

Since coastal landscapes support a variety of environments, it is important to set out some general definitions. This is especially important because the terms 'coast(al)', 'marine' and 'maritime' are often used interchangeably with only passing reference to their specific meaning (Bailey et al., 2015:44; Erlandson and Fitzpatrick, 2006). In recognising these problems, recent work has sought to provide clearer definitions. Erlandson and Fitzpatrick (2006:8-9) differentiate between 'coastal' and 'maritime' adaptations. They define 'coastal adaptations' as 'any subsistence lifestyle based along *the margins* of a large body of water that includes the regular use of foods from aquatic habitats' while 'maritime adaptations' are defined as 'those cases where humans regularly used boats for travel and subsistence purposes, where voyaging away from the immediate coastline was possible, and where the majority of nutrition (calories or protein) was derived from marine resources' (Erlandson and Fitzpatrick, 2006:8-9). Marean (2014:20) suggests a similar set of definitions (see also Jeradino, 2016b; Will et al., 2016, 2019). However, these definitions tend to focus on ecotones associated with, or seaward of, the shoreline. The 'coast' also exerts a significant influence on ecotones located immediately landward of the shoreline. As Bailey et al. (2015) have pointed out, the term 'coastal' can refer to a large region of variable extent, possibly extending many kilometres inland. This landscape is often referred to as the 'coastal plain'. It contains ecotones under the influence of both terrestrial and marine processes, often encompassing flora and fauna unique to this zone and economically attractive to hunter-gatherers (see below). Yet, simply lumping the coastal plain in with the 'marine' (or even 'maritime') terms risks creating a generalisation so broad that it lacks any conceptual usefulness (Bailey et al., 2015; Hallam, 1977).

In light of these considerations, we suggest slightly revised definitions. First, following Erlandson and Fitzpatrick (2006:8-9) and Marean (2014:20), 'maritime' here refers to the zone, and all resources, that lie to seaward of the intertidal zone beyond pedestrian foraging accessibility that require watercraft technology for access (see also Fa, 2008:2203-2204). 'Maritime adaptations' are defined by economic accessibility to this zone but importantly can also be defined by archaeological technology (e.g. Balme, 2013) or cultural (e.g. McDonald, 2015) indicators for access to the maritime zone where the majority of nutrition does not necessarily have to derive from maritime sources (c.f. Erlandson and Fitzpatrick, 2006). 'Intertidal' refers to the area of coastline periodically exposed and inundated by tides but, importantly, are accessible by pedestrian foraging and do not require watercraft technology. 'Marine' is used more generally and refers to the zone permanently or tidally submerged by ocean waters incorporating both the maritime and intertidal zones. The 'coastline' or 'shoreline' is used to refer to the narrow zone where land meets the sea (but see Larcombe et al. 2018). The 'coastal plain' refers to all those zones occurring landward of the shoreline where ecosystems are significantly influenced by proximity to the ocean or other variables unique to this zone (e.g. slope, exposure to on-shore winds etc.). Finally, 'coast' is used more generally here, referring to all those zones, which uniquely occur due to oceanic proximity, and that are accessible by pedestrian foraging. The 'coast' then subsumes the coastal plain, the shoreline and the intertidal zone. These definitions, and their wider discussion in the literature, ultimately show that the maritime, marine, coastal and intertidal zones are spatially and temporarily dynamic zones which resist easy definition.

The coast can be an extraordinarily productive and resource-rich environment. Coastal gross primary productivity is around 2000 kcal/m^2/yr, which is twice as productive as the open ocean, while the primary productivity of estuarine and intertidal zones can reach 10 times this level (Fa, 2008:2195, and references therein; Woodroffe et al., 1988, 1989). However, the coast incorporates more than just marine resources. It is a 'super-ecotone' where a mosaic of terrestrial and marine habitats co-exist over small distances, often including freshwater environs in the form of rivers, creeks, springs and seeps (Bailey et al., 2007, 2008; Bailey and King, 2011:15; Barker, 1999; Bicho et al., 2011:xviii; Erlandson and Braje, 2015:34; Erlandson et al. 2015; Hallam 1987; Perlman, 1980:281). Although coasts tend to be relatively productive environments, they are not uniformly productive across space or time (Erlandson, 2001:331-332). Instead, a variety of processes operating on different scales dictate the structure of coastal landscapes. Larcombe et al. (2018) provide a detailed review of the fundamental physical processes that define coastal morphology and change across space and time. For example, slope, tidal amplitude, wave action, bathymetry, sedimentation (erosional or depositional), oceanographic variables (e.g. sea level fluctuations, dominant currents, primary productivity, upwelling, salinity and sea surface temperature), climate and tectonics can all significantly structure coasts and their relative productivity (see also Bailey and King, 2011; Bailey et al., 2007; Bird, 2008; Chappell and Thom, 1977:278-279; Davidson-Arnott, 2010; Fa, 2008; Fa and Sheader, 2000; Lambeck and Chappell, 2001; Lambeck and Nakada, 1990; Lambeck et al., 2002, 2014; Lewis et al., 2011; Jennings, 1971; Murray-Wallace and Woodroffe, 2014; Perlman, 1980; Pye and Allen, 2000; Semeniuk, 1995; Siddal et al., 2003; Webster et al. 2018). Indeed, these processes have left complex signatures on now-drowned coasts with varying consequences for the preservation of archaeological deposits (e.g. Brooke et al., 2017).

Sea level fluctuation, being the most prominent temporal coastal process throughout the Pleistocene, deserves some expanded discussion. Indeed, between 18,000 and 8,000 years ago sea levels around the Australian margin rose 130m (Ishiwa et al., 2016; Lewis et al., 2013). There can be no doubt that long-term Pleistocene sea level fluctuations resulted in localised coastal alteration or re-organisation including a constant dynamic flux in productivity, resource structure and the organisation of occupation (Bailey and King, 2011; Bird, 2008; Chappell and Thom, 1977; Davidson-Arnott, 2010; Erlandson and Fitzpatrick, 2006; Hepp et al., 2019; Hinestrosa et al., 2016, 2019; Jennings, 1971; Larcombe et al. 2018; Reeder-Myers et al., 2015; Williams et al., 2018; Woodroffe, 1990; Woodroffe et al., 1988:96-97). In Australia, sea level regime (i.e. regression or transgression) has been argued to play a major role in determining coastal productivity and configuration (see Allen et al., 2020; Beaton, 1985; Bowdler, 2010; Chappell, 1993, 2000; Chappell and Thom, 1977; Grindod et al., 1999; Hall, 1999; O'Connell et al., 2010). Regressive phases have been associated with river entrenchment, swamp contraction, modest mangrove development, saline flats and lower levels of productivity where sediments tend to accumulate in alluvial valleys instead of the shore and/or bypass the estuarine system altogether due to river entrenchment. Transgressive phases have been associated with more productive estuaries, lagoons and coral reefs where sediment often becomes trapped within the coastal system, contributing towards the expansion of swamps and estuarine environments (e.g. Grindrod et al., 1999; Johnson et al., 1982). Of course, the exact influence of any regressive or transgressive regime will be dependent on local coastal structure and the pace and magnitude of sea level change (Hinestrosa et al., 2016, 2019; Larcombe et al., 2018; Ward et al., 2015; Webster et al., 2018). One well-studied example of coastal dynamism under a transgressive regime can be sourced from work on Australian mangroves in the Alligator Rivers region of the Northern Territory, which exhibit extraordinary diversity in their responses to early-to-mid-Holocene sea level rise (see Chappell and Thom, 1977; Clark and Guppy, 1988; Grindod et al., 1999; Jennings, 1971; Proske et al., 2014; Semeniuk, 1983, 1994, 1995; Thom et al., 1975; Ward et al., 2015; Wolanski and Chappell, 1996; Woodroffe, 1990; Woodroffe et al., 1985, 1988, 1989, 1993). Ultimately, although sea level fluctuation is a global phenomenon, its impact on coastal environments and resident populations varies locally because all coastal settings interact with sea level fluctuation uniquely.

3 Pleistocene Coastal Occupation in Australia: A Review of Evidence, Significance and Issues

3.1 Earliest Evidence and Coastal Colonisation

It is widely agreed that Sahul was settled by 'behaviourally modern' people sometime before 50,000 years ago (Balme, 2013; Balme et al., 2009; Bradshaw et al., 2019, 2021; Clarkson et al., 2015, 2017; Hiscock, 2013, 2015; Miller et al., 2016a, 2016b; O'Connell et al., 2018; Smith, 2013; Veth et al. 2017c). Sahul sits at the end of the Southern Dispersal Route and its settlement required maritime (specifically, watercraft and cordage) technology to make a water crossing of up-to 120km indicating that, not only was the settlement of Sahul a coastal one, but that the settling population also possessed a coastal and maritime adaptation (Balme, 2013; Balme et al., 2009; Bird et al., 2018, 2019; Birdsell, 1977; Bowdler, 1977; Chappell, 2000; Hiscock, 2013; Jones, 1979; Kealy et al. 2016, 2017; Kuijjer et al. 2022; O'Connell and Allen, 2012, 2015; O'Connell et al., 2010; O'Connor and Chappell, 2003; O'Connor and Veth, 2000; Szabo and Amesbury, 2011). The evidence from Sahul and its nearby Pleistocene islands is, outside of Africa, among the earliest coastal archaeological evidence associated with *Homo sapiens* and provides some of the only conclusive evidence for coastal and maritime adaptations on the Southern Dispersal Route (Barker 2013; O'Connor et al. 2011; Leavesley and Allen 1998; Veth et al., 2017c). Indeed, there is currently very little archaeological evidence for pre-glacial coastal occupation between eastern Africa and South East Asia, leaving a >10,000km long gap along the Southern Dispersal Route with supporting evidence only from the beginning (e.g. Marean et al. 2011) and the end (Bailey et al., 2015; Bulbeck, 2007; Erlandson and Braje, 2015; but see Walter et al., 2000; cf. Bailey and Flemming, 2008:2156; Bailey et al., 2007:146-147, 2015:52). Whichever routes were taken, the evidence shows that, at least by the time people reached Wallacea, they were exploiting coastal resources (e.g. Leavesley et al., 2002; O'Connor, 2007; O'Connor et al., 2011). Recent modelling shows that the now submerged coastal margins were likely to have been key corridors of movement for the earliest populations (Crabtree et al., 2021).

3.2 A Coastal Time Lag in Australia?

Even though maritime adapted people began the settlement of Sahul, the Australian evidence for Pleistocene coastal occupation and resource use is rare until the mid-to-late Holocene (Bowdler, 1995; Chappell, 2000; O'Connell et al., 2010; O'Connor and Veth, 2000; Richards 2012; Rowland et al. 2015; Ulm, 2011, 2013). As Barker (1999:119) noted, 90% of the dated coastal sites in Australia only retain evidence for mid-to-late Holocene coastal occupation (e.g. Ulm 2011). This archaeological phenomenon was initially used to argue that Pleistocene to early Holocene sea level fluctuations inhibited coastal productivity until mid-to-late Holocene sea level stabilisation allowed productive conditions to develop facilitating coastal occupation (Beaton, 1985; Callaghan, 1980; Hughes and Lampert, 1982; Lampert and Hughes, 1974; Mulvaney and Kamminga, 1999; Rowland, 1983, 1999; Walters, 1989). Perhaps the most well-known example is Beaton's (1985) time-lag hypothesis based on research at Princess Charlotte Bay in north Queensland. The absence of shell middens pre-dating approximately 4,700 BP led Beaton to conclude that coastal occupation did not occur until 1500 years after the marine transgression had stabilised. Beaton attributed this to the post-glacial marine transgression which, he argued, prevented productive coastal ecosystems from forming and that, even following sea level stabilisation (6000 years ago), coastal environments 'lagged behind' as they slowly regained productivity. Once productivity levels were sufficient, coasts were occupied by Aboriginal people resulting in the mid-to-late Holocene coastal archaeological record (Beaton, 1985).

This argument was quickly rebutted by other Australian researchers in both Western Australia and Queensland (Barker 1999, 2004). In northwest Australia both Veth (1993; Veth et al., 2007) and Morse (1988, 1993a, 1993b; see also Przywolnik, 2002) found evidence for Pleistocene to early Holocene coastal economies. Morse (1993a; see also O'Connor, 1999; Veth, 1999) suggested that, despite changes in sea level, coastal resources were always part of past Aboriginal economy and, as sea levels fluctuated, people followed the sea. In the coastal Kimberley, evidence from Koolan Shelter 2 also demonstrated that marine resource use was well established during the terminal Pleistocene (O'Connor, 1999). In Tasmania, Rocky Cape South and Cave Bay Cave both contain relatively dense shell middens that include fish remains dating to around 7000 – 8000 BP as the sea rose to its current position (Bowdler, 2010; Jones, 1968). Furthermore, off the coast of Queensland on the Whitsunday Islands, Barker (1991, 1999, 2004) demonstrated marine resource use from archaeological deposits at Nara Inlet 1 and Border Island 1 in association with sea level rise. Barker suggests that this provides good evidence for both the resilience of Aboriginal coastal occupation and productive marine environments in the face of sea level transgression (see also Rowland et al. 2015). Although, as noted by Rowland et al. (2015:158) and Rowland et al. (2021), McNiven et al. (2014) have recently recast the time-lag hypothesis to explain delayed settlement patterns on islands in Shoalwater Bay in Queensland.

3.3 Models for Australian Pleistocene Coastal Occupation and Productivity

While some further evidence for Australian Pleistocene marine resource use has since been found (e.g. Przywolnik, 2002; Richards 2012; Veth et al., 2007), on a continental scale, evidence for Pleistocene coastal occupation remains rare and ephemeral. Bowdler (2010) has even suggested that much of the eastern Australian coast was relatively unproductive and unattractive during the Pleistocene resulting in little occupation (see also Mulvaney and Kamminga, 1999). As a result, many scholars have argued that the early settlement of Australia largely occurred in the interior where coasts were subsequently populated from savannah landscapes (e.g. Chappell, 2000; Hiscock, 2008, 2015; Hiscock and Wallis, 2005; O'Connor and Chappell, 2003; O'Connor and Veth, 2000; Smith, 2013; see also Hallam, 1987; Horton, 1981). In this literature, marine resources are generally perceived as *ad hoc* additions to, or part of a more generalised mixed, economy and do not become important until the Holocene (e.g. O'Connor and Veth, 2000; but see Morse, 1993a, 1999). In recognising the emergent terminal Pleistocene evidence for coastal occupation, Beaton (1995:798-802) proposed a dichotomous model that distinguished procumbent coastlines (gentle slope, low relief and low wave energy environments) from precipitous coastlines (high relief and slope with high wave energy). During the last marine transgression, the latter should be more productive because of their relative stability. Beaton (1995) rejected the sparse and terrestrially mixed Pleistocene marine resource archaeological assemblages as evidence for a 'coastal economy', reiterating that coastal economies (archaeological assemblages dominated by marine fauna) are only a mid-to-late Holocene phenomenon under 'highly productive' stabilised coastal environments (see also Smith, 2013; Hiscock, 2015).

Beaton's (1995) dichotomous model also formed part of a colonisation model for Australia by O'Connell and Allen (2012, 2015; Allen and O'Connell, 2020; O'Connell et al., 2010; but see Veth et al. 2007). Upon reaching Sahul, O'Connell and Allen (2012:7) suggest that coasts were used in association with movement into the interior but that precipitous and procumbent coastal patches were ranked differently (O'Connell and Allen, 2012:8). They argue that shellfish on precipitous shorelines will redistribute quickly in response to sea level change because of their steep slopes and rocky substrates but, because precipitous intertidal zones are narrow, high ranked prey species were quickly depleted by predation (see also Codding et al. 2014). In contrast, O'Connell and Allen (2012:8) argue that shellfish on procumbent shorelines, although locally abundant and resistant to over-predation, were devastated by sea level change, with overall productivity only recovering well after sea level stabilisation (*sensu* Beaton, 1985). They argue that although precipitous shorelines are highly ranked patches, their potential to be rapidly depleted meant that more permanent occupation of areas adjacent to precipitous coastlines only occurred after Holocene sea level stabilisation (*sensu* Beaton, 1985, 1995). As most Pleistocene and early Holocene archaeological coastal sites have been recorded from precipitous coastlines and contain sparse marine fauna (e.g. Morse 1993a; Przywolnik, 2002), O'Connell and Allen (2015:76) suggest their predictions are supported. As such, they argue that Australia was largely settled via the interior where high-ranked terrestrial patches were targeted.

However, the coastal component of O'Connell and Allen's (2012) model has been criticised due to its over-emphasis of the vulnerability of coastal productivity due to sea level fluctuations, especially on 'procumbent coasts' (Ditchfield et al., 2018; Erlandson, 2012; Manne and Veth, 2015; Veth et al., 2014, 2017b, 2017c; Ward et al. 2014, 2015). These critiques have proposed that Pleistocene marine ecosystems were productive and able to respond quickly to sea level change, being in dynamic equilibrium with the coast if sediments were available. It is suggested that this was especially the case for 'procumbent coasts', since broad, low-relief, coastal plains likely provided significant opportunity for sediment accumulation resulting in productive coastal environments with abundant resources for coastal foragers. Veth et al. (2014) cite evidence for continued marine resource use from transgressing, relatively broad and low-relief ('procumbent') coasts since 14,000 cal. BP in northwest Australia. Richards (2012) work at Cape Duquesne in southwest Victoria provides further evidence for early Holocene marine resource use with a variety of coastal shell middens returning dates from 11600 – 8600 cal. BP, while Nunn (2020) has recently shared several Aboriginal histories about people interacting with the post-glacial marine transgression. Assumptions about the vulnerability of large shellfish to predation are also open to challenge based on results showing long-term sustainability of shellfishing in areas with high productivity but likely low populations (e.g. Ulm et al., 2019). It also is worth noting that Pleistocene sea level fluctuation was not always constant and that sea levels may have stabilised under productive conditions for short periods. For example, O'Leary et al. (2020) recently identified a relict drowned MIS3 shoreline from a previous stabilised period with potentially productive components such as estuaries and lagoons (see also Brooke et al., 2017).

In response to some of this literature, O'Connell and Allen (2015:76) have argued that sedimentary substrates would often require centuries to re-form as a result of sea level fluctuation and that productive coasts, especially the 'procumbent' type, were rare until mid-Holocene sea level stabilisation. They reaffirm that the correlation of early 'near-coastal' sites adjacent to steep shelves fits with their predictions whereby only precipitous coasts will be productive and therefore attractive to early populations (O'Connell and Allen, 2015:76). Williams et al. (2018:151) have also suggested that, since the precipitous northwest coastal sites are constrained by desert or arid environments, there was little other alternative beyond marine resources for the past occupants of these coastal locations.

It is worth noting here, that procumbent coasts supported many more resources than simply shellfish. Hallam (1987) originally made this point in response to Bowdler's (1977) coastal colonisation model, arguing that coasts include significant hinterland habitats such as swamps, lakes, floodplains and savannah, and that these likely contributed a significant proportion of coastal diet. Importantly, this also includes terrestrial plant resources which, due to their limited preservation in the archaeological record, often receive less attention in reconstructions of past coastal diets (Roberts et al., 2020). Veth et al. (2007, 2014, 2017b; Ditchfield et al., 2018) have repeatedly stressed the existence of such a broad-based economy for the northwest coastal plain for over 42,000 years despite sea level fluctuation. Indeed, during a review of important Australian palaeoclimatic records, De Deckker et al. (2020:24) have also suggested that the Pleistocene coast "would have nurtured more human activity during the settlement of this landmass".

3.4 Southeast Asian Evidence from Sahul

No review of Pleistocene coasts for Sahul would be complete without the evidence from southeast Asia. Freshwater resources appear to be the earliest exploited aquatic fauna, with remains of freshwater molluscs from the sites of Kao Pah Nam in Thailand (700,000 BP) and Trinil in Java (500,000 BP to 400,000 BP) thought to have been procured by *Homo erectus* (Choi and Driwantoro, 2007; Joordens et al., 2014; Ono, 2016). In terms of Anatomically Modern Humans, Szabo and Amesbury (2011) noted that early sites in this region are also characterised by freshwater rather than marine mollusc exploitation. For example, at Niah Cave in Borneo, modest quantities of freshwater molluscs have been recovered dating back to 50,000 BP, along with the remains of freshwater turtles (Piper and Rabett 2014; Szabo and Amesbury 2011). Later in the sequence, the inclusion of greater quantities of estuarine taxa attest to shifting coastlines in the early Holocene (Szabo and Amesbury 2011).

Early evidence for the exploitation of marine resources have been recovered from Laili Cave (44,000 BP), Asitau Kuru (formerly known as Jerimalai, 42,000 BP), Gua Makpan (40,000 – 38,000 BP), Buang Merabak (41,000 BP) and Matenkupkum (41,000 BP). These assemblages display either use of near-shore marine resources and/or the exploitation of pelagic fish (e.g. Scombrids exploited between 42,000 – 38,000 BP at Asitau Kuru) since occupation (Hawkins et al., 2017; Kealy et al. 2020; Leavesley and Allen, 1998:75; O'Connell et al., 2010: 60; O'Connor and Chappell, 2003:17; O'Connor et al., 2011, 2017a; but see Anderson, 2013a, 2013b; Bailey, 2013; Erlandson, 2013; cf. O'Connor and Ono, 2013 for debate about Asitau Kuru).

Dating to 37,000 BP, the earliest evidence for the manufacture of shell beads in Southeast Asia has been located from Asitau Kuru, in the form of an *Olivia* bead (Langley et al. 2016). The preference for, and use of, *Olivia* beads is attested by their presence not only throughout the Asitau Kuru sequence, but also from the nearby sites of Lene Hara and Matja Kuru 1 and 2. Some of the earliest evidence for complex fishing technology worldwide, is found from the sites of Matenbek and Asitau Kuru, dating to 22,000 BP (Allen et al., 1988; O'Connor and Ono, 2013; Smith and Allen, 1999; c.f. Langley et al. 2021; but see Yellen et al., 1995). At Gua Makpan, the recovery of 239 specimens relating to fishing technology and dating to the last 15,000 years, demonstrates the importance and wide-ranging use of marine shell for these activities (Langley et al. 2021). Ornamental artefacts were also manufactured at Gua Makpan (Kealy et al. 2020) and Asitau Kuru (Langley et al. 2016), from *Nautilus* shell. (see also Langley and O'Connor, 2017 and Langley et al., 2019 for a review). Langley et al. (2016) suggest that Asitau Kuru's archaeological record, with its production of ornamental artefacts and manufactured fishing technology, indicates a coastal adaptation in which the coastal landscape was intertwined with the social realm. The recovery of fish-hook technology in association with a terminal Pleistocene burial at Tron Bon Lei (Alor Island), further demonstrates the social and cosmological connection that the coast and its marine resources had for the Pleistocene inhabitants of Southeast Asia (O'Connor et al., 2017b).

Like many sites worldwide with Pleistocene coastal signatures (e.g. Erlandson, 2001), Szabo and Amesbury (2011) note that many of these sites are located next to steep bathymetry where most sites are likely located within 1km of LGM shorelines. For example, evidence of pre-Holocene exploitation of precipitous coasts can be found in northern New Guinea, along the steep Vanimo coast in West Sepik province (Gorecki et al., 1991; O'Connor et al., 2011). Watinglo and Lachitu Rockshelters contain evidence of terminal Pleistocene/Holocene coastal use, although early dates of 30,444 – 29,380 and 29,065 – 28,000 cal. BP obtained from marine shellfish in Lachitu Rockshelter imply this site may have had a longer occupation sequence (O'Connor et al., 2011:9). Both sites contain dense zones of marine shellfish, with the Lachitu assemblage representing a diverse suite of habitats, including rocky, sandy, reef and mangrove (Gorecki et al., 1991; O'Connor et al., 2011; also see Summerhayes et al., 2017 for further review). However, given the limited nature of overall Pleistocene coastal exploitation, Szabo and Amesbury (2011: 12) question whether coastal ecosystems, especially estuarine ones, were ever stable in the region during Pleistocene sea level fluctuation. Following Terrell (2004), Allen and O'Connell (2020) have also suggested that reefs, lagoons, swamps and floodplains along the northern New Guinea coast were replaced by unproductive rocky coasts with entrenched rivers during the glacial, an argument that they suggest can be extended to Sahul's steep rocky coasts. They suggest this environmental shift may have acted to restrict mobility and isolate Sahul from Wallacea during the LGM. Following the LGM and from the terminal Pleistocene onward, there is a rapid rise in marine resource use represented in sites throughout the region (transgression and stabilisation; see Ono et al., 2020; Szabo and Amesbury, 2011), which includes evidence for pelagic fishing and complex maritime technology especially on islands depauperate in terrestrial fauna (e.g. Carro et al., 2016; Kealy et al., 2020; O'Connor et al., 2018).

3.5 Remarks on Pleistocene Coasts in Australia

Clearly, many issues remain for Pleistocene coastal archaeology in Australia but there are perhaps two especially pertinent questions. First: why is there still so little evidence for Pleistocene coastal occupation in Australia? The notion that Pleistocene coasts were largely unproductive and only supported ephemeral occupation on precipitous shorelines provides one possible answer. Sea level rise drowning most of the evidence for Pleistocene coastal occupation provides another. This brings us to the second pertinent question: independent of occupation, were Pleistocene coasts productive? This review has shown that the nature of Pleistocene coastal productivity is contested. Building from this review and drawing on international and national palaeo-environmental literature, we now discuss, analyse and assess the current evidence for Australian Pleistocene coastal productivity and occupation.

4 Regional Pleistocene – Early Holocene Coastal Occupation and Productivity in Australia: A Discussion

This discussion has two major aims. First, to assess how much of the coastal record was drowned and, from that discussion, assess the representativeness of the record that remains. Second, to assess whether Australian Pleistocene coasts were productive based on current coastal palaeoenvironmental and archaeological research.

4.1 How Representative is the Coastal Record?

Many scholars have argued that most pre-Holocene coastal zones were drowned, eroded or buried by rising seas during the terminal Pleistocene, thereby making earlier coastal records inaccessible and creating a false impression of a global mid-to-late Holocene 'coastal efflorescence' (Bailey and Flemming, 2008; Bailey and Milner, 2002:4; Bailey et al., 2015; Bicho and Hawes, 2008; D'Alpoim Guedes et al., 2016; Erlandson, 2001:300; Erlandson and Fitzpatrick, 2006; Parkington 1980; Rick et al., 2005:176). Indeed, as Bailey et al. (2007:130-131, 138, 2015:43) point out, for most of human existence sea levels generally oscillated between -40m to -60m below present levels, meaning that, if people occupied these coastal zones, the majority of pre-Holocene coastal archaeology will have since been submerged. Therefore, at the global scale, the largely terrestrial archaeological record may not be fully representative of human evolution, dispersal, and environmental interaction and may provide a biased, perhaps misleading and incomplete picture (Bailey and Flemming, 2008:2157; Bailey and Milner, 2002:4-5; Bailey and King, 2011:15; Bailey et al., 2007:131; Erlandson, 2001; Erlandson and Braje, 2015; Erlandson and Fitzpatrick, 2006:6; Perlman, 1980:296). This may also be true for the Australian record.

This argument assumes that sea level rise was significant enough to submerge most archaeological deposits that would otherwise provide evidence for widespread Pleistocene coastal occupation. This assumption should be tested on a case-by-case basis where the question could be framed as: under conditions of significant Pleistocene coastal occupation, should there be conclusive evidence for coastal occupation preserved in terrestrial contexts today? If the answer is 'yes', then the relative lack of evidence for Pleistocene coastal adaptations may be a genuine behavioural phenomenon (or perhaps the product of limited sampling). If the answer is 'no', then we must confront the fact that the archaeological record under-represents coastal occupation and consequently consider what a Pleistocene coastal adaptation might look like. One way to begin addressing the question for Australia is to consider the average distance within which archaeological evidence for coastal occupation is likely to occur from palaeoshorelines. There is good evidence to consider that distance from palaeoshorelines may play a significant role in the archaeological visibility of coastal occupation. Both ethnographic and archaeological literature indicate that archaeological sites located more than 5 – 10km from the coast are unlikely to contain substantial evidence for marine resource use. Even distances in the order of only 1 – 2km will dramatically reduce the archaeological density of marine fauna as it becomes mixed with other sources of subsistence (Bailey, 2013:889; Bailey and Flemming, 2008:2155; Bailey and Milner, 2002:5; Bicho et al., 2011; Bird and Bird, 1997; Dusseldorp and Langejans 2013; Erlandson, 2001; Fa, 2008; Jeradino, 2016a; Meehan, 1982; Wing, 1977). For example, Meehan (1982) shows that shellfish remains are rarely transported to residential sites >10km from shorelines except in situations where the shells themselves have utilitarian or symbolic value (e.g. Smith and Veth 2004). Bailey and Flemming (2008:2155; Bailey and Milner, 2002) have suggested that the optimum zone for shell midden accumulation is within 1km of the shore, while Dusseldorp and Langejans (2013) have documented similar patterns archaeologically for the South African Middle Stone Age. Jeradino (2016a) also shows that shell weight densities drop by half beyond 2km from the South African coast in Holocene deposits. Drawing from these observations, we suggest that coastal sites will contain evidence for marine resource use, but this evidence will become increasingly sparse and dominated by more proximal (coastal plain terrestrial) resources with increasing distance from the coastline until evidence for dietary marine resource use drops away to utilitarian or symbolic marine resource use only (as suggested by Meehan, 1982).

For Australia, an average distance within which archaeological evidence for Pleistocene coastal occupation is likely to occur from palaeoshorelines can be calculated using the presence of dietary marine fauna (e.g. non-utilitarian shellfish) as a positive archaeological indicator of coastal occupation. Drawing on the Australian literature for Pleistocene coastal occupation, Table 1 presents this average value calculated based on the distance to a generic palaeoshoreline (using the sea level curve in Ward et al., 2015 paired with bathymetry where possible) at the time when marine fauna is first registered in known Pleistocene deposits. This value can then be compared with the distance of currently available terrestrial sampling points to palaeoshorelines at different points in time. If the latter distance is greater than the former, then it is possible to suggest that evidence for coastal occupations is unlikely to be preserved in terrestrial sampling points. This simple approach avoids problems with marine faunal density (after Jeradino, 2016a) but does not account for other factors like processing costs and marginal returns of other food items (e.g. Codding et al., 2014). Of course, there are significant limitations with this approach including geomorphology and plate tectonics which impact our ability to accurately reconstruct the position of past shorelines using only generic sea level curve data and bathymetry (e.g. Larcombe et al. 2018). As such, we suggest the values presented in Table 1 be viewed as an approximate guide with an arbitrary error range of ± 2km. With these limitations in mind, our basic approach provides a heuristic but coarse-grained device with which to address the question posed above.

Table 1. Tabulated distances to palaeoshorelines for 12 sites at the time when the first marine fauna occurs. Distances to shoreline were calculated using Ward et al.'s (2015) sea level curve and bathymetry in ArcGIS or quoted distances in text. Calibrated dates derive from Ditchfield (2018) and Ditchfield and Morse (in prep) while uncalibrated dates were calibrated using either ShCal20 or Marine20 with local reservoir correction if available. Where possible, dates which derive from the closest stratigraphic or excavation units to the first evidence for marine fauna were selected.

Site	**Source**	**First Marine Fauna (cal. BP)**	**Distance to Palaeoshoreline (km)**
Jansz Rockshelter	Przywolnik (2002)	39,140	11.3
C99 Cave	Przywolnik (2002)	37,512	11.8
Mandu Mandu Creek Rockshelter	Morse (1993a)	36,227	5
Pilgonaman Creek Rockshelter	Morse (1993a)	12,979	5.1
Yardie Well Rockshelter	Morse (1993a)	11,536	5.1
Boodie Cave	Veth et al. (2017c)	48,000	18.6
Noala Cave	Veth et al. (2007)	13,794	40.4
John Wayne Country Rockshelter	Ditchfield et al. (2018)	14,932	37.2
Koolan Shelter 2	O'Connor (1999)	11,577	2
Bridgewater South Cave	Lourandos (1983)	11,500	3.75
Koongine Cave	Bird and Frankel (2001)	11,000	15
Cape Duquesne Middens	Richards (2012)	11,100	1.3
Average		-	13.1

The heuristic analysis of Australian Pleistocene sites suggests that most evidence for marine resource use will accumulate within 13.1 ± 2 km of shorelines with increasing abundance towards it. A review of bathymetry shows that, in most instances, the current Australian shoreline is more than 13.1 ± 2 km distant from palaeoshorelines until the terminal Pleistocene (Figure 1). Figure 1 shows the Australian terminal Pleistocene shoreline at 12,000–13,000 cal. BP along with the possible palaeoshoreline at 13.1 ± 2 km from the current Australian coastline. It shows that only four major areas should register coastal archaeological records at this time: northwest Australia (especially Cape Range), some areas of South Australia, Tasmania and a portion of the New South Wales coast (see Williams et al., 2018 for comparable results). Before this time, sea levels were always lower. While we know there is a record of coastal archaeology in the northwest, there are only a few Pleistocene coastal records for the other areas and none that date to before 13,000 cal. BP. This likely results from a lack of targeted sampling and substrate type (e.g. alluvial plains on the New South Wales coast and sea cliffs in South Australia and Victoria; see Bird, 2008). Although, given that coasts are dynamic, not all coasts were productive during the Pleistocene in Australia, meaning that it is possible that the lack of Pleistocene coastal records for parts of the four identified regions may be a real phenomenon (as argued by Bowdler 2010 for much of the east coast).

Overall, however, this basic analysis suggests most Pleistocene (especially dense) evidence for marine resource use will be drowned especially before 12,000 – 13,000 cal. BP. As such, it should come as little surprise that almost no Pleistocene shell middens (e.g. greater than 50% shell matrix) are known on contemporary shorelines and that, where Pleistocene marine faunal remains are present (e.g. Cape Range), they are sparse and mixed with terrestrial fauna. For example, in southwest Victoria, both Bridgewater South and Koongine Caves register sparse marine faunal assemblages mixed with terrestrial fauna during the Pleistocene – Holocene transition when these locations were between 3 – 15km from the shoreline (Bird and Frankel, 2001; Lourandos, 1983; Richards, 2012). By comparison, nearby middens at Cape Duquesne, dating to the same period and being only 1km distant from the shoreline, are dominated by economic shellfish (Richards, 2012). This example shows that we should generally expect dense economic marine faunal assemblages to accumulate close to palaeoshorelines. Indeed, it is then no coincidence that Erlandson (2001:321-323; see also Bailey and Flemming, 2008), in his seminal review of coastal archaeology, found that only one trait correlates with the preservation of early coastal archaeological records, and that was steep bathymetry (i.e. short distance of the current coastline to palaeoshorelines). Almost no early coastal sites were present adjacent to shallow bathymetry ('procumbent shelves').

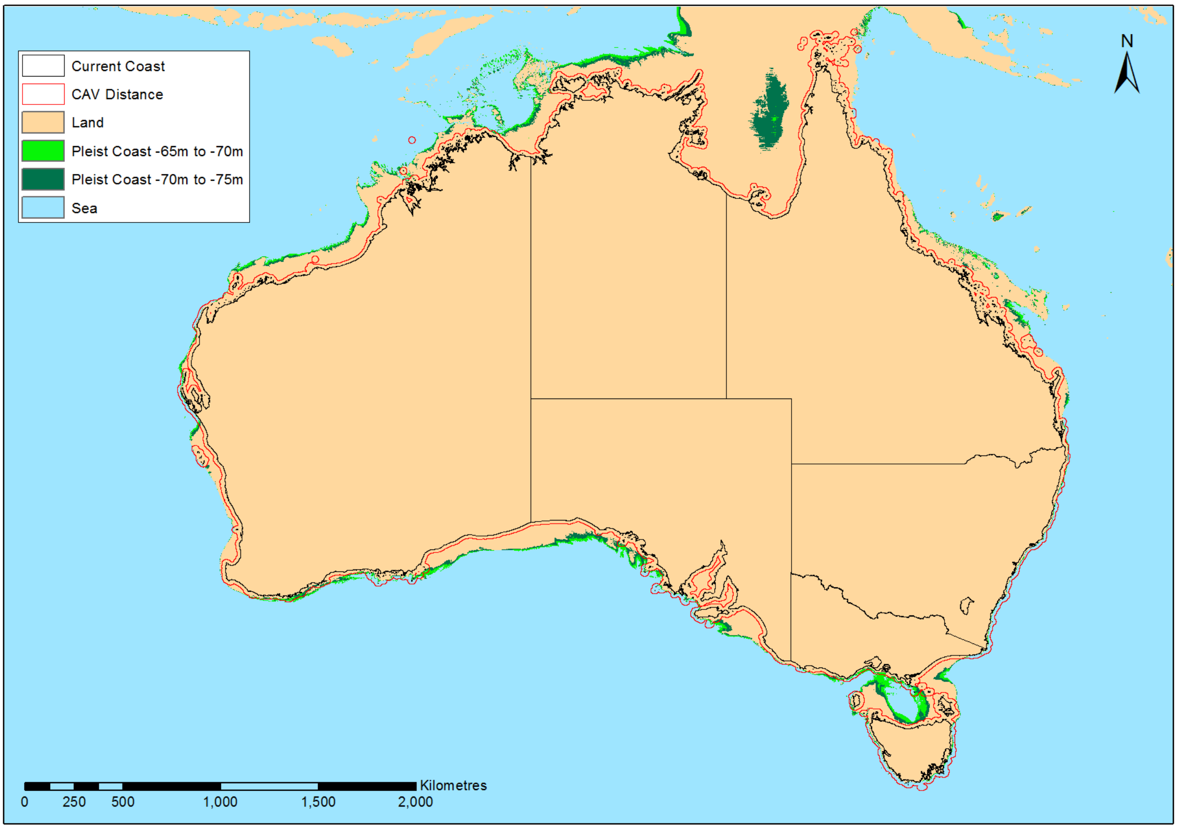

Figure 1. Map showing the Australian continent at 12,000 – 13,000 cal. BP with the possible 13.1km palaeoshoreline and Pleistocene coastal zones within -65 to -75m depth superimposed.

Returning to the question posed above then, it is possible to provide a preliminary answer. Unless the current coastline is within approximately 13.1 ± 2 km from palaeoshorelines, there is unlikely to be extensive evidence for coastal exploitation in terrestrial contexts in the form of marine resource use, and especially shell middens. Even in steep shelf scenarios (e.g. Cape Range), evidence for significant marine exploitation is unlikely to be dense beyond 1 – 2km from palaeoshorelines (i.e. the 'optimum zone'; Bailey and Flemming, 2008:2155). Rather, the expectation should be that only sparse and mixed marine-terrestrial assemblages should remain from Pleistocene coastal occupations at least until the terminal Pleistocene to early Holocene. Therefore, it is unlikely that the Australian Pleistocene archaeological record provides a representative account of settlement and occupation since the coastal record is predominantly missing. Morse (1993a) recognised this phenomena some time ago:

> The relative paucity of evidence for use of the coast during the late Pleistocene, compared to that for the Holocene, should not be a surprise. The profusion of shell middens along the modern Holocene shoreline provides unequivocal evidence that

> the preferred location for the consumption of gathered marine resources such as shellfish is the immediate coastal/littoral periphery (Morse, 1993a:278).

4.2 Coastal Marine Resource Productivity

Having established the likelihood of Pleistocene coastal bias resulting from submergence, it is pertinent to consider whether past coastlines were productive environments and whether they could support populations.

In Australian research, transgressive regimes have often been associated with higher marine productivity while regressive regimes have been argued to be depauperate (Section 2). O'Connell and Allen's (2012:8, 2015:76) model does vary from these simple depictions. Their model posits that sea level transgression on procumbent coasts would be destructive, preventing sedimentary stabilisation and marine productivity due to easily inundated low relief shelves. Although, Veth et al. (2014, 2017b) and Ward et al. (2013, 2014, 2015) have since pointed to robust archaeological evidence for marine productivity along procumbent coasts under post-LGM transgressive regimes such as the presence of *Terebralia paulustris* remains dating to periods of sea level transgression (see also Barker, 1991, 1999, 2004; Ditchfield et al., 2018; Manne and Veth 2015; O'Connor, 1999 for further archaeological evidence). Numerous macro-tidal estuaries across northern Australia also show significant early-to-mid-Holocene estuarine productivity and sedimentation in conjunction with sea level transgression (e.g. Proske et al., 2014). As Bailey et al. (2015:44) argue, sea level rise brings significant marine benefits including increased nutrient recycling from the seabed to the photic zone (water surface) as productive shallow shelves replace steeply shelving offshore topography. In a similar vein, Woodroffe (1990:488) notes that, given the widespread evidence for resilient early Holocene mangrove communities in northern Australia, large river mouths on Australia's continental shelves must have possessed deltaic and estuarine ecosystems throughout their landward retreat. This corroborates the general idea that transgressive regimes can promote marine productivity, challenging the notion of unproductive procumbent coasts (Beaton, 1995; O'Connell and Allen, 2012). Indeed, the number of sites which show evidence for significant coastal occupation under transgressive sea level conditions is internationally increasing (e.g. Colonese et al., 2011; Dillehay et al. 2017; Goodbred et al., 2020; O'Connor et al., 2018; Pardo et al., 2016; Prendergast et al., 2016; Reitz et al. 2016; Szabo and Amesbury, 2011; and references therein for each). This burgeoning record strongly suggests that transgressive coasts can be productive in many instances, with the possible exception of very rapid sea level rise in the order of ≥6.1 mm year^{-1} (Saintilan et al. 2020). We conclude here that there is little basis to assume that Pleistocene coasts were categorically low in marine productivity during transgressive regimes.

This leaves us to consider the effects of regressive regimes, and especially during glacial periods, on coastal productivity. In contrast to assumptions of regressive marine zones being unproductive (Section 2.2), Ward et al. (2013, 2015) have emphasised that periods of regression can produce broader coastal plains which will generally propagate larger tidal ranges and create greater opportunity for sediment accumulation, both of which can enhance marine productivity. For example, Fa's (2008) work demonstrates that broader coasts are characterised by larger tidal amplitudes which can support large intertidal molluscan biomasses that are capable of withstanding significant intertidal exploitation. However, it is worth noting that palaeotides were not the same as those observed today (Haigh et al., 2019), with changes in sea level effecting tidal resonance on the continental shelf (e.g. in the Timor Sea). Recent exploration of the effects of changing sea level on tidal range and currents by Kuijjer et al (2022) indicates lower tidal regimes (4m tidal range as opposed to present day scenario of 5.65m) along the northern Australian shelf and Bonaparte Gulf in MIS 4 regressive phases. This indicates that whilst a broad 'procumbent' coast was exposed, tidal range and therefore the intertidal zone was not as great as today in this region, whilst other regions had greater tidal regimes.

In addition, sea level regression - transgression can create a greater total continental shoreline meaning that, should some marine zones be productive, there may be greater total opportunity to exploit them. For example, the changing shorelines of the modern Great Barrier Reef region across the Holocene transgression can be considered through quantifying sinuosity, a measure of the departure of the shape of the coastline from a straight line. Figure 2 shows the coastline of northeast Australia at approximately modern levels (8,000 BP) and lowstand (≥15,000 BP), with an intermediate figure at -50m showing thousands of islands created around last interglacial reef and landscape features. This, in theory, would not only increase length of coastlines but also the extent of intertidal zones and, ultimately, marine productivity.

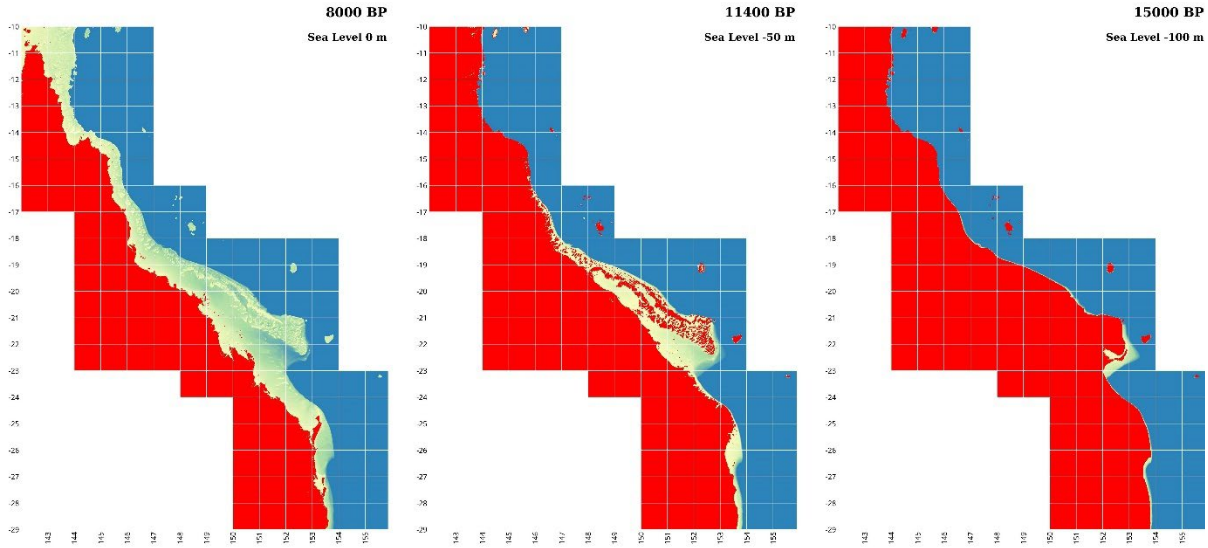

Figure 2. Queensland coastline shown at selected time-slices. Red indicates extent of terrestrial coasts and islands. Note that islands identified in the 11,400 BP time-slice include topographic features from Holocene reef-growth. However, the general pattern reflects landforms created during the last interglacial period.

While these ideas may support regressive marine productivity in theory, direct evidence for marine productivity on regressive shorelines is required. Following Chappell's (1993; Chappell and Thom, 1977) suggestions, marine productivity can be characterised by reasonably high sedimentation in the near-shore zone in association with dietary marine fauna. Recent research addresses these criteria.

Ishiwa et al. (2016) recently obtained an offshore core from the last glacial coastline of the Bonaparte Basin. Shell fragments appear from 29,000 cal. BP, including *Anadara* sp., indicating estuarine conditions as sea level receded towards the Bonaparte coast. On the same Bonaparte Basin glacial coast, De Deckker and Yokoyama (2009) and Fogg et al (2020) track coastal evolution under regressive conditions where open marine conditions grade into shallow marine, marginal marine and then to estuarine brackish conditions. Fogg et al (2020) use industry collected 3D seismic data to map shoreline position along with changing littoral and estuarine features in the Bonaparte Gulf. Preliminary results support the available core data, indicating the now submerged shelf hosted palaeofluvial systems, estuarine areas and regions with potential for mangrove growth in low stand periods. Using the core data, De Deckker and Yokoyama (2009:87) note that dense molluscan remains accumulated under shallow water conditions including bivalves, echinoid spines and scaphopods, while, in the brackish sediments are insect remains and vegetal fibres which strongly suggests heavy continental freshwater influence. De Deckker and Yokoyama (2009) even recovered fish fragments from brackish, estuarine units during fully glacial periods. The density of shellfish and the thickness of shell layers also demonstrates rapid sedimentation during this time. The Bonaparte core records definitively show that productive marine conditions were associated with regressing shorelines and that they remained productive throughout the Last Glacial Maximum. Although this is only one example from one coastline, it is critical because it shows that, at the very least, regressive marine zones were not universally unproductive. Beyond the Bonaparte Gulf, modelling by Hinestorsa et al. (2016) suggests that sediment accumulation may have been significant during both regressive and transgressive regimes at the Noggin Passage, potentially leading to productive estuaries and mangrove systems on parts the Pleistocene Great Barrier Reef (GBR) coast. Webster et al. (2018), using drill cores, also show that the GBR was resilient to both regressive and transgressive regimes, never being completely 'decimated' by sea level fluctuation. In Africa, there are also numerous examples of continued coastal occupations during Pleistocene regressive conditions (e.g. Jeradino 2016a, 2016b; Loftus et al., 2019; Niang et al., 2018; Will et al., 2016, 2019; see also Zilhao et al., 2020).

As such, we conclude that current models for Pleistocene marine productivity in Australia may under-estimate the resilience of marine ecosystems in response to sea level fluctuations (Erlandson, 2001, 2012; see also Barker, 1999, 2004). While we already have some evidence for coastal occupation on regressive and transgressive coasts from northwestern Australia (see above), there is no reason other coasts across Australia could not be intensively occupied where marine resources were systematically exploited. Indeed, coasts may very well have served as refugia during the LGM (Morse 1993), a subject of further planned work at Cape Range in northwest Australia by the authors. Internationally, there are also examples of coastal occupation during glacial conditions. For example, based on oxygen isotopic analyses, Prendergast et al. (2016) have shown that late glacial coasts were occupied year-round at Haua Fteah in Libya. Such analyses may yield similar results in Australia.

4.3 Coastal 'Terrestrial' Productivity

One of the outstanding issues in considering Australian coastal productivity is that most research only considers the marine zone when assessing productivity (e.g. Section 3; but see Hallam, 1987). However, researchers are beginning to illustrate that coastal economies will also include suites of terrestrial coastal plains fauna and flora (Bailey et al., 2008; Ditchfield et al., 2018; Erlandson and Braje, 2015:34; Hallam, 1987; Klein and Bird, 2016). The coastal plain is an important component of the coast for mobile coastal hunter-gatherers. After-all, coastal hunter-gatherers do not live in the intertidal zone, they occupy the coastal plain and so should be expected to use its resources. Essentially, a coastal economy occurs *from the land* and the interoperability of the two zones is theoretically and practically unified (see Roe 2000).

In this context, it is significant that most Pleistocene coasts fronted much larger coastal plains than at present and there is good reason to believe that at least some were very productive. Faure et al. (2002) have observed that emergent Pleistocene coastal plains were likely well-watered environments, even dubbing them as 'coastal oases'. This is because sea water columns exert significant pressure on continental ground-water reservoirs when the water column lies over the continental shelf (high sea levels). Under conditions of lower sea level, when the water column pressure is removed from the continental shelf, groundwater can become emergent across the shelf in the form of springs, soaks and streams. As Faure et al. (2002:52-53) note, a 120m drop in sea level is equivalent to raising the continental water table by 120m. This effect will be particularly profound on large, wide, low relief shelves (of which Australia has many; Yokoyama et al., 2001) where significant water columns are resident during high sea levels. Indeed, the northeast Australian coastline likely hosted large freshwater lagoon systems before sea-level rise breached the continental shelf, with karstified hills along the continental margin from previous reef building episodes during high stands blocking the outlet of rivers to the shelf edge (Woolfe et al., 1998; Dunbar and Dickens, 2003). Benjamin et al. (2020) have also located evidence for the availability of freshwater on the Pleistocene coast in the form of drowned freshwater springs near Cape Bruguieres, Murujuga.

Under these conditions, sources of coastal freshwater were likely available throughout the Pleistocene. Indeed, during arid glacial conditions (when ground-water accessibility may have been, theoretically, at its greatest), the coast possibly represented a very significant refugium for terrestrial flora, fauna and people even in the absence of productive marine ecosystems. Bailey et al. (2007) have made similar suggestions for Arabia while Dusseldorp and Langejans (2013) have suggested that some coastal plain sites may have been preferentially occupied to maximise terrestrial coastal resource exploitation. Manne (1998) proposed that a rich range of resources became available during the Pleistocene-Holocene transition in the area of the

Montebello Islands, as groundwater levels relating to changes in sea level increased the availability of near-surface freshwater, which in turn increased productivity in the coastal hinterlands. Ditchfield et al. (2018) have suggested that both marine and coastal plain ecosystems were economically integrated during the terminal Pleistocene on Barrow Island. Indeed, perhaps coastal plain resources were the main drawcard for some Pleistocene coastal hunter-gatherers where any settlement strategy capable of effectively exploiting *both* terrestrial and inter-tidal zones would carry a significant advantage (Bailey and King, 2011:19-20; see also Kyriacou et al., 2014). Interestingly at Gua Makpan on Alor Island (Indonesia), and other sites from isolated Wallacean islands, Roberts et al (2020; see also Kealy et al., 2020) used stable isotope analyses of human teeth to reconstruct the diet of past cave occupants during the Pleistocene and Holocene. The archaeological record at Gua Makpan indicates a focus on marine subsistence during occupation which began at 40,208 – 38,454 cal. BP. Initial reliance on urchins and barnacles expanded to a wide range of gastropods and bivalves as well as medium-sized inshore fish and Scombridae (mackerel, bonito and tuna). Terrestrial macrovertebrates are only present as a minor component throughout the sequence and includes giant rats, fruit bats and turtles (Kealy et al., 2020). However, the isotopic analysis from Gua Makpan and other sites shows the diet includes a broader use of terrestrial interior resources, particularly after 20,000 cal. BP (Roberts et al., 2020). If this analysis is correct, it would indicate that, even on islands adjacent to steep shelf topography, coastal occupation did not solely focus on marine foods but actively incorporated accessible terrestrial components which may also include plant resources. As Roberts et al. (2020:8) suggest, the stable isotopic data highlights the need to pay further attention to the potential contribution of plant and terrestrial animal resources to human diets on tropical islands and, as we might suggest, to coastal settings more generally.

In future discussions it may be useful to differentiate between coastal and marine adaptations where the former is characterised by the use of both coastal terrestrial and marine resources while the latter is characterised by systematic use of marine resources (cf. Jeradino, 2016b). One way to test this proposition is through detailed examination of archaeological faunal and floral assemblages (see below). Overall, we suggest that the archaeological record of coastal plains will be just as critical as sites immediately adjacent to the shore for reconstructing past coastal adaptations (Erlandson, 2015; Erlandson et al., 2011; Jones, 1977).

5. Future Directions

We have argued that most of the evidence for Pleistocene coastal occupation in Australia is now submerged, which logically explains why there is so little recoverable evidence and, when it does occur, it is adjacent to 'precipitous' coasts. Based on available literature in association with archaeological and palaeoenvironmental evidence, we have suggested that there is no reason to assume that coastal landscapes were unproductive or unoccupied. This discussion provides a framework for conceptualising the occupation of Pleistocene coasts that are currently drowned and largely inaccessible for sampling purposes. It also provides a platform with which to consider future research and what additional evidence might be required to develop our understanding of Australian Pleistocene coasts. As with some other global study areas, we might now consider how the systematic use of coastal resources on productive Pleistocene coasts would be expressed archaeologically over space and time.

We identify three major areas for future research: faunal studies, stone artefact research and coastal modelling. Of course, there are further areas of future work including geomorphology (e.g. Jeradino 2016a; Ward et al. 2017, 2018) and underwater archaeology on submerged sites (e.g. Benjamin et al. 2020; Benjamin and Ulm 2021; McCarthey et al. 2022) but we wish to focus on these three here.

5.1 Faunal Research

So how might we move forward, with much of our Pleistocene coastlines lying submerged beneath the sea? One way is to further explore the nature of diet breadth in coastal sites. While few sites exist for interrogating coastal faunal records of the late Pleistocene to early Holocene in northern Australia, some of the best evidence for coastal living is in the Montebello-Barrow Islands complex. Records from Noala, Haynes and Boodie Caves suggest that as the coastline progressively came closer to these sites, people took advantage of an increasingly diverse range of resources from a variety of marine and terrestrial habitats (Manne and Veth, 2015; Veth et al., 2017; Veth et al., 2007). Both the greatest intensity of site use and diversity of taxa recovered, occur when the coastline was within 0-10km of these sites (Manne and Veth, 2015; Veth et al., 2017; Veth et al., 2007).

If viewed from the perspective of evolutionary ecology, broad diets are traditionally associated with a lowered abundance of higher ranked resources, with diet diversification following a reduction in encounter-rates with highly ranked resources (Stephens and Krebs, 1986). The broad diet observed in the Montebello and Barrow Island sites could thus be interpreted as being driven by a limited abundance of higher-ranked prey, compelling people to include a broad selection of prey items in their diet. However, in northwest Australia there is little evidence for narrow diets from even the earliest phases of occupation and instead, early sites suggest that a broad diet was the norm. For example, interior sites such as Riwi and Carpenters Gap demonstrate that a diverse suite of taxa were targeted, from earliest settlement onward (Balme et al., 2019; Maloney et al., 2018). In the northwest of Australia, a broad diet may not be indicative of a response to a reduction in higher-ranked prey, but instead, signify the most parsimonious diet for a region with a diversity of small to medium bodied game coupled with either sporadic or highly seasonal precipitation. Perhaps then, coastlines may have always been particularly attractive due to the additional resources afforded from the combination of marine and coastal hinterland habitats.

Recent work by Dillehay et al. (2017) on sites on the Chicama coast of northern Peru lends support for the view that coastal environments were appealing in terms of their rich diversity of resources. At 15,000 cal. BP, the coastline was approximately 30km to the west of the current Chicama coast and by 10,000 cal. BP, the coast was 8 – 10km away (Dillehay et al., 2017). However, already 15,000 years ago, people in this region were exploiting shoreline, estuarine and hinterland resources in the form of both fauna and flora while also indicating a familiarity with more interior resources. Dillehay et al. (2017) argue that the abundance of resources provided by the intersection of different ecological zones in this region encouraged coastal settlement and consequently slowed migration into the interior.

Turning back to northwest Australia, we argue for a renewed focus on the Cape Range-Barrow-Montebello region. This is an area known for its unique, well-preserved archaeological and faunal record and has excellent potential for improving our understanding of how people utilised and moved between the diverse sets of resources that likely occurred between the hinterland and the coast. Our understanding of what diet breadth over time actually means in this region would be improved by examining larger sample sizes of fauna. By comparing multiple faunal assemblages from across this region, issues of sample size – which so often plague our understandings of past economies in northern Australia – may be alleviated, allowing for a more detailed and nuanced understanding of the past 50,000 years.

5.2 Stone Artefact Research

There is very little research on stone artefact assemblage formation processes or technology on Pleistocene coasts, which makes this an important research area. How do the technologies and assemblage patterns on Pleistocene coasts compare with those in other terrestrial environments? If coasts were regularly occupied during the Pleistocene, technological patterns may differ significantly from better documented inland areas. Since stone artefacts also preserve well in the archaeological record, they will be critical for identifying drowned archaeological sites (Stanford et al., 2014). Stone artefact assemblages can also be used to reconstruct important regional-scale behavioural processes such as mobility. We know little about Pleistocene coastal mobility, though occupation is currently thought to be short-term (O'Connell et al. 2012). The mobility of past people is also linked with environmental productivity where certain mobility patterns are linked to the spatial and temporal structure of resources throughout a landscape (e.g. Binford, 1980, 1982; Brantingham, 2006; Grove, 2009; Hamilton et al., 2016; Kelly, 2013). In this way, targeted research on available assemblages can help reconstruct little known mobility patterns, which will also help inform on Pleistocene coastal productivity.

One of the key areas that is worth highlighting is sourcing the stone artefacts discarded across Pleistocene coasts. Sourcing provides one measure for the distance and direction of human movement, and connects the point of discard with the source location (e.g. quarried outcrop or secondary deposit; e.g. Ditchfield et al. 2021). This may have significant potential for Pleistocene coasts since sourcing non-local stone artefacts may link interior landscapes with the coast, possibly demonstrating trade networks or seasonal movements. Ditchfield and Ward (2019) have begun sourcing work using Pleistocene coastal assemblages from Cape Range and Barrow Island. While their goal was to establish the source locations for locally derived lithologies, this research also established which raw materials were non-local. For example, on Barrow Island, both stratified and open assemblages contain non-local lithologies that derive from igneous or siliceous sedimentary source locations. None of these occur on the island so must derive from the present-day mainland or now-drowned source locations. Further work will help pinpoint the source locations for these non-local materials.

5.3 Coastal Modelling and Submerged Archaeology

Coastal modelling can be a key tool in helping to generate an understanding of past occupation on Pleistocene coasts and, to date, has taken many forms. For example, predictive models can be used to inform on the potential locations that submerged archaeological sites might preserve. The modelling work undertaken by Veth et al. (2019) for Murujuga provides an example of predictive modelling. Veth et al. (2019) argued for a multi-staged assessment strategy for examining the possible continuity of terrestrial and maritime archaeological landscapes. Terrestrial site patterning through time was based on a large sample of dated middens and occupation sites, considering marine processes, and surviving contexts. Based on this terrestrial dataset, targeted marine survey can be deployed at various scales using remote sensing, diving, and coring (Benjamin et al., 2018). The predictive model concluded there were five likely targets for submerged sites ranging from well stratified and structured occupation sites including middens through to lag deposits of artefacts and stone features on hardpan. Grøn et al (2022) have recently critiqued how the application of analogue topographical models, along with their assumptions of productivity, resource distribution through time and inundation, will likely be far more complex than continuity models and thus both the accurate location of submerged sites and their dating in Australia are in their infancy (e.g. Benjamin et al. 2020)

Important components of shorelines can also be established using modelling techniques based on industry derived seismic data. O'Leary et al. (2020) have done this for the North West Shelf around Barrow Island and the Montebello Islands. Their analysis has identified features of a past stable coastline including dune systems likely dating to MIS3 (57 – 29k). This shows that sea levels were stable enough to produce prominent features for a period during MIS3 and that this coastal landscape included tidal flats, estuarine channels, coastal lagoons and a coastal plain some 15km wide. O'Leary et al. (2020) argue that these environments likely produced a productive marine ecosystem including mangrove communities like the present-day Pilbara coastline. High-resolution palaeogeographic reconstructions have also been undertaken using 2D and 3D seismic data in the Bonaparte Gulf (Fogg et al., 2020). Seismic interpretation alongside extant core data allows the mapping of changing coastal configurations, including palaeochannels, estuaries, headlands, and offshore islands (Fogg et al., 2020). This can form the basis for mapping the potential locations and preservation states of submerged sites too. Sub-bottom profiling is another critical step for future modelling and palaeoshoreline mapping since it corrects for the impact of post-transgressive sediments on offshore platforms (Erlandson, 2021). Modelling of the maritime environment and palaeolandscape to include ocean circulation models and Pleistocene tidal models (for instance, Kuijjer et al., 2022) will also allow for a better in-depth understanding of maritime and coastal conditions, which will aid understanding of coastal productivity and maritime mobility.

Locating evidence for submerged archaeology on the continental shelf is clearly an important next step. This effort is well underway, Benjamin et al. (2020) have recently reported the first submerged Aboriginal archaeological site with >200 stone artefacts recorded at Cape Bruguieres located off the Murujuga coastline. Minimum dates place site occupation before 7000 cal. BP. While there are many difficulties with locating and investigating drowned sites in Australia (see Benjamin et al., 2020; Benjamin and Ulm 2021; McCarthy et al. 2022; Veth et al. 2020), we believe this will be the first of many Aboriginal archaeological sites located in drowned marine contexts which, ultimately, adds credence to our suggestions that most of the Australian Pleistocene coastal archaeological record is drowned (Section 4.1).

6 Conclusion and Final Remarks

Although numerous spatio-temporal processes condition the exact productivity of any given coastline, Pleistocene coasts can be conceptualised as potentially productive but taphonomically biased (through sea level rise and associated processes). The discussions and arguments put forward in this paper provide a basic framework, and a different set of environmental expectations, within which to assess independently reconstructed occupation patterns to those proffered by other models for Pleistocene coastal occupation in Australia (e.g. Beaton, 1995; O'Connell and Allen, 2012). We believe that the case for Pleistocene coastal occupation and coastal (marine and terrestrial) productivity is high. We do not believe that stable coasts (without fluctuating sea levels) are a prerequisite for productivity. Instead, we believe that the lack of archaeological evidence for coastal occupation and marine resource exploitation in Australia is mostly due to a drowned record lying on continental shelves with only terrestrial-marine mixed assemblages persisting in areas of relatively steep continental relief. This may seem like an obvious conclusion to some, but our review of the literature has shown that this is not uncontested. Regardless, while most of the record for previous coastal occupation lies submerged on continental shelves, the behaviour of people, such as mobility across these extensive landscapes, remains poorly understood. In order to recalibrate the terrestrially biased archaeological records to be more representative and inclusive of Pleistocene coastal occupational patterns, it is now crucial that more research is undertaken targeting landscapes that can provide Pleistocene coastal windows, such as continental islands and uplands once close to the shelf such as Cape Range. A new generation of research is planned for both these areas and for submerged records off the southern and northeast tropical coasts.

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