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Sea-level change and demography during the last glacial termination and early Holocene across the Australian continent

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ABSTRACT

Future changes in sea-level are projected to have significant environmental and social impacts, but we have limited understanding of comparable rates of change in the past. Using comprehensive palaeoenvironmental and archaeological datasets, we report the first quantitative model of the timing, spatial extent and pace of sea-level change in the Sahul region between 35-8 ka, and explore its effects on hunter-gatherer populations. Results show that the continental landmass (excluding New Guinea) increased to 9.80 million km^2 during the Last Glacial Maximum (LGM), before a reduction of 2.12 million km^2 (or ~21.6%) to the early Holocene (8 ka). Almost 90% of this inundation occurs during and immediately following Meltwater Pulse (MWP) 1a between 14.6 and 8 ka. The location of coastlines changed on average by 139 km between the LGM and early Holocene, with some areas >300 km, and at a rate of up to 23.7 m per year (~0.6 km land lost every 25-year generation). Spatially, inundation was highly variable, with greatest impacts across the northern half of Australia, while large parts of the east, south and west coastal margins were relatively unaffected. Hunter-gatherer populations remained low throughout (<30,000), but following MWP1a, increasing archaeological use of the landscape, comparable to a four-fold increase in populations, and indicative of large-scale migration away from inundated regions (notably the Bass Strait) are evident. Increasing population density resulting from MWP1a (from 1/655 km^2 to 1/71 km^2) may be implicated in the development of large and complex societies later in the Holocene. Our data support the hypothesis that late Pleistocene coastal populations were low, with use of coastal resources embedded in broad-ranging foraging strategies, and which would have been severely disrupted in some regions and at some time periods by sea-level change outpacing tolerances of mangals and other near-shore ecological communities.

1. Introduction

The potential impacts of late Pleistocene (<65 ka) sea-level change on Aboriginal populations and societies has long been a subject of speculation by Australian archaeologists and historians. Over four decades ago, Blainey (1975:89–91) hypothesized that: 'In one way or other the rising seas disturbed the life of every Australian for thousands of years. Salt water drowned perhaps one-seventh of the land … Most tribal groups on the coast 18,000 years ago must have slowly lost their entire territory … a succession of retreats must have occurred. The slow exodus of refugees, the sorting out of peoples and the struggle for territories probably led to many deaths as well as new alliances.' This view was recently reiterated by Griffiths (2013:167): 'The advancing coastline pushed people inland, forcing local crowding, the mixing of cultures, and, most likely, causing conflict'.

Archaeologists have long recognised that Aboriginal people would have occupied the now-drowned continental shelves

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surrounding Australia (Jones, 1968; Lampert and Hughes, 1974; Bowdler, 1977; White and O'Connell, 1982; Dortch, 1996; O'Connell and Allen, 2015), but opinions have been divided about the nature of occupation and the significance of sea-level rise. Mulvaney and Kamminga (1999) argued against widespread evacuations as coastlines advanced, arguing that regions that were most impacted by broad shelves only hosted small populations, while Nunn (2016) and Callaghan (1980) have argued that low-stand coastlines would have been steeply shelving and 'an unattractive prospect for settlement'. More recently, O'Connell and Allen (2015) hypothesized that for a range of ecological and environmental factors, coastal resources would have been quickly depleted by hunter-gatherers and prompted greater inland use prior to the LGM. Similarly, Beaton (1985:17) has proposed that the coasts were little used before the Holocene and that the 'present coasts offer no compelling evidence that they began to receive coastal refugees at any time between 8000 and 5000 thousand years ago'. A similar conclusion was reached for the southeast of Australia by Bowdler (2010). In contrast, Lewis (1988) suggested the opposite, relating sea-level-rise-induced demographic changes in Arnhem Land to alliance-making – symbolised in the appearance of the composite Rainbow Serpent in rock art. Numerous excavations along the west coast of Australia also show exploitation of marine resources by hunter-gatherer populations through the terminal Pleistocene at locations that have always been close to the sea (Morse, 1988, 1993; Przywolnik, 2002, 2005; Veth et al., 2007, 2017). To date, however, these debates have largely been conceptual, and based on limited or no quantitative data. Here, we bring together two comprehensive datasets of past demography and sea-level change for Australia to provide such data, and contribute to the human-sea-level interaction debates.

In the last decade, significant progress has been made in our understanding of past Aboriginal demography. This is in large part the result of continental and regional models of demography and mobility created using radiocarbon data (e.g. Smith et al., 2008; Williams, 2013; Williams et al., 2013, 2015b). The use of radiocarbon data as a proxy for human activity, generally in the form of sum probability or time-series analyses, is an approach first explored in the 1980's (Rick, 1987), and has been further developed and applied in the archaeological literature in Australia and internationally (e.g. Ulm and Hall, 1996; Gamble et al., 2005; Turney and Hobbs, 2006; Surovell et al., 2009; Shennan et al., 2013; Williams, 2013; Timpson et al., 2014). These models show that Pleistocene populations across Australia were strongly influenced by climatic and environmental change (Williams et al., 2015a) which is most strongly expressed during the heightened aridity of the Last Glacial Maximum (LGM) (21±3ka), when populations appear to fall back into ecological refuges to survive, abandoning large tracts of the continent, and with subsequent egression only in the early Holocene (Veth, 1993; Williams et al., 2013, 2015a; cf. Tobler et al., 2017). While hunter-gatherers can be seen to react to major geo-temporal climatic events in these models, exploration of their response to sea-level change has yet to be undertaken.

As one of the most tectonically stable continents with limited isostatic influence, the Australian continent has been a keystone of Quaternary sea-level studies for over 30 years (e.g. Hopley, 1983; Thom and Roy, 1983, 1985; Woodroffe et al., 1986; Lambeck and Chappell, 2001; Murray-Wallace and Woodroffe, 2014). Recently, a synthesis of this research has been developed as part of the OZ-INTIMATE initiative (Lewis et al., 2013), and provides a consensus view of sea-level change over the last 25,000 years. The synthesis identified that the Australian continent was subject to: i) sea-level that was 125 m lower than present prior to, and during the LGM (see also Ishiwa et al., 2016); ii) a rapid rise between 14.6 and 14.3 ka (MWP1a) followed by a continuing increase through to 8 ka; and, iii) increasing regional variation for the timing and scale of a mid-Holocene high-stand before present levels were attained in the last few thousand years (Sloss et al., 2007, in review; Lewis et al., 2008, 2015; Fogwill et al., 2017). Our study combines these data with additional available sea-level data back to 35 ka (Lambeck et al., 2002) to compare with the archaeological and demographic record.

Here, we explore the interactions and response of past Aboriginal societies to sea-level change at a continental scale. Using established demographic and land-use models with the latest consensus view on sea-level change, we identify how much land was lost to inundation, how rapidly, and consider what effect this may have had on past populations. Given the response of hunter-gatherers to other major geo-temporal impacts over the last 50,000 years (e.g. the mega-aridity of the LGM, and European arrival), we explore the role of changing sea-level on demographic and behavioural change.

2. Material and methods

We focus our analysis between 35 and 8 ka, a period of time encompassing the available sea-level consensus data, including the most substantial changes in sea-level since colonization of Australia. This time period also contains a relatively detailed archaeological record, which is limited prior to 35 ka.

Here we use radiocarbon (^{14}C) data from the AustArch dataset as a proxy of past human activity and demographic change (Williams et al., 2014b). The AustArch dataset is the most comprehensive radiocarbon dataset for the Australian continent, comprising 5044 radiocarbon dates from ~1750 archaeological sites. Of these, 951 ages from 322 sites are from the period 35–8 ka. The archaeological data come from a range of site types, including rockshelters, open sites, middens, fish traps, and burials, and includes both terrestrial and marine samples. There have been a small number of additional sites dated to the 35–8 ka interval reported since the publication of AustArch, most notably Boodie Cave (WA) (Veth et al., 2017) and Warratyi rockshelter (SA) (Hamm et al., 2016), but these do not affect the overall trends of the dataset, and have been incorporated in the discussion and figures where relevant.

For palaeo-populations, we re-ran demographic models developed by Williams (2013). These used statistical transformation of the AustArch dataset to develop annual percentage growth rates (GR_{Ann}) or birth rates, and quantitative estimates of hunter-gatherer numbers across Australia at 200 year intervals over the last 50 ka (see Supplementary Data). We also explore the amount of land utilized by past populations through time using a cluster analysis and minimum bounding rectangle approach developed by Williams et al. (2013) and (2015a) (see Supplementary Data). This analysis defines spatially bounded radiocarbon data from similar time periods to provide quantitative estimates of areas or territories occupied by hunter-gatherers. When combined across Australia, the data provide an overall indication of the amount of land used, and an indirect proxy for mobility of past populations.

To determine sea-level change, we used data from the continent-wide curve compiled from several sea-level proxies (including mangrove mud/peat/wood, wood, peat, corals, shell material, ooids and foraminifera) by Lewis et al. (2013). We pre-appended the sea-level data from Lambeck et al. (2002) to extend this synthesis to 35,000 years. Specifically, we interpolated a line of best fit through the estuarine indicators (i.e. mangrove material, intertidal bivalves) and between the terrestrial (wood, peat - i.e. relative sea-level lower than terrestrial indicators) and marine (coral, shell/carbonate material, foraminifera and ooids - i.e. relative sea-level higher than marine indicators) proxies to report data at 200-year intervals (as metres below relative present mean sea-