



The process, biotic impact, and global implications of the human colonization of Sahul about 47,000 years ago



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ABSTRACT

Comprehensive review of archaeological data shows that Sahul (Pleistocene Australia-New Guinea) was first occupied by humans ca. 47 ka (47,000 years ago); evidence for earlier arrival is weak. Colonizing populations remained low – perhaps two orders of magnitude below those estimated at European contact – for many millennia, and were long restricted to relatively favorable habitats. Though human arrival coincided with changes in native flora and fauna, these were mainly the products of climatic factors, not human interference. The genetic makeup of founding populations and their arrival date are consistent with the Late Dispersal Model of anatomically modern humans beyond SW Asia, beginning ca. 50 ka. Early Dispersal Models (120–70 ka) are not refuted, but draw no support from the Sahul record as currently understood.

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1. Introduction

A decade ago, we presented two critical reviews of evidence for the date at which humans first occupied Sahul (Allen and O'Connell, 2003; O'Connell and Allen, 2004). Continuing dispute about this issue, recent improvements in chronometric techniques, and reports of new sites and dates led us to undertake another assessment, the details of which are presented elsewhere (Allen and O'Connell, 2014). Here we summarize key elements of that exercise and consider their implications for current ideas about the process of Sahul colonization, its impact on terrestrial habitats and resources, and the timing of anatomically modern human dispersals beyond Africa.

2. Background

In the 1980s, it was argued that anatomically modern humans had colonized Sahul by 40 ka (e.g. White with O'Connell, 1982; Flood, 1983; Allen, 1989). The coincidence with the earliest dates for the European Upper Paleolithic suggested that both developments were part of the same process: the rapid dispersal of

modern humans from Africa across Eurasia and ultimately into Sahul 40–45 ka (e.g. Cann et al., 1987; Stringer and Andrews, 1988). Subsequent reports of 50–60 ka luminescence dates from two archaeological sites in Arnhem Land (Roberts et al., 1990, 1994), Malakunanja II (now called Madjedbebe) and Nauwalabila, challenged this notion. Proponents of these early dates observed that the Sahul chronology was based mainly on radiocarbon dating, that 40 ka was at or near this method's operational limit, and that small amounts of contamination could result in “old” samples yielding much younger apparent ages (Roberts et al., 1994; Chappell et al., 1996). Dates from the two Arnhem Land sites were widely viewed as important indicators of the limits of radiocarbon dating and of the more likely age of Sahul colonization. The challenge to broader arguments about ex-African human dispersal chronologies, also based on radiocarbon dating, was implicit but obvious.

Some maintained that, despite concerns about sample contamination, the date for Sahul colonization might well have been about 40–45 ka, consistent with then standard European and broader Eurasian models (e.g. O'Connell and Allen, 1998). These commentators raised crucial questions about the Arnhem Land sites, specifically about the stratigraphic relationships between dated media (energy trapped in sand grains) and archaeological phenomena (stone tools) at these two locations (e.g. Bowdler, 1990; Hiscock, 1990; O'Connell and Allen, 1998). If these relationships were not secure, any argument about the anthropological implications of the dates was meaningless.

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Our 2003/2004 reviews concluded that people had arrived and spread widely across Sahul by 43–45 ka, but found that evidence for an earlier presence, particularly one >50 ka, was weak. Our conclusion was broadly consistent with some aspects of then-current arguments about the effect of human arrival on indigenous megafauna (e.g. Roberts et al., 2001), but contradicted other ideas about a purported pre-50 ka arrival and impact, not only on native plant and animal communities but also on regional climate systems (e.g. Miller et al., 1999). Equally important, our assessment provided a basis for estimates of mitochondrial DNA (mtDNA) mutation rates, which in turn contributed to the development and critique of various Upper Pleistocene ex-African human dispersal scenarios (e.g. Endicott et al., 2009; Henn et al., 2012; cf. Oppenheimer, 2009; Petraglia et al., 2010). Nevertheless, a >50 ka arrival date is still asserted in some quarters (e.g. Cane, 2013; Hiscock, 2013; Smith, 2013; Oppenheimer, 2014). No final resolution of this issue has yet been achieved, and it remains crucial to arguments about the process of Sahul colonization and its impact on indigenous fauna and flora, as well as to ongoing disputes about the timing of Upper Pleistocene human diasporas and the identities of the populations involved.

Recent developments in dating technology provided the basis for an updated review. These include: 1) more frequent use of pre-treatment methods that extend the applicability of radiocarbon dating back to ca. 50–55 ka (Bird et al., 1999); 2) widespread use of accelerator mass spectrometry (AMS) as a means of generating more precise estimates of radiocarbon content (but see Hogg et al., 2013; Allen and O'Connell, 2014:87); 3) construction of calibration curves that allow accurate calendar-age estimates from ¹⁴C dates for samples much older than a previous limit of ca. 26 ka (e.g. Bronk Ramsey et al., 2012; Reimer et al., 2013), and 4) new radiocarbon and luminescence dates from sites previously described, as well as from those reported for the first time following our 2003/2004 reviews.

3. Sahul sites dated 40–47 ka

Table 1 lists the 26 archaeological sites or localities that offer relatively reliable, relatively well-published evidence of an anatomically modern human presence in Sahul, Wallacea and the Bismarck Archipelago by about 40,000 years ago. The two oldest dates for the occupation of Tasmania (ca. 38–39 ka) are also noted. Fig. 1 provides a graphic summary of this information; Fig. 2 shows the distribution of all sites listed in Table 1. All radiocarbon dates were calibrated by reference to OxCal 4.2, using the IntCal 13 curve. The Southern Hemisphere offset SHCal 13 was not applied since dates derived from that routine in this age range fall within the standard deviations of unadjusted determinations. A further seven recently reported sites with claimed archaeological dates 40–47 ka are not referenced here because of incomplete information on stratigraphic provenience, relationships with evidence of human presence, or the dates themselves (Allen and O'Connell, 2014). Their inclusion would have no significant effect on this discussion.

Early dates from 21 sites were determined solely by radiocarbon, those from another three by a combination of radiocarbon and luminescence, and those from the remaining four by luminescence or U-series analyses. Most radiocarbon samples were subjected to acid-base-acid or acid-base-oxidation-stepped combustion (ABOX-SC) pretreatment; all but three (from GRE 8, Matenkupkum, Upper Swan) were analyzed by accelerator mass spectrometry. All carbon dates were derived from charcoal or shell collected from sedimentary strata containing evidence of human activity. The oldest dates from four sites (Devil's Lair, Menindee, Riwi, PACD H1) pertain to samples retrieved from anthropogenic thermal features (probably hearths or roasting pits) and are

regarded as especially secure with respect to their implications for the date of human presence. Luminescence and U-series age estimates were derived from sediment samples and are generally marked by much wider confidence intervals (Fig. 1).

4. What about Nauwalabila and Madjedbebe?

As indicated above, excavations at Nauwalabila and Madjedbebe (both located north of Nawarla Gabarnmang, Fig. 2) yielded stone tools in association with sediments dated by luminescence at 50–60 ka (Roberts et al., 1990, 1994). Detailed re-analysis of data from Nauwalabila showed that the relationship between artifacts and dated sediments was probably the result of post-depositional disturbance, and that claims for human presence at this location greater than about 40 ka were unsupportable (Allen and O'Connell, 2003; cf. Bird et al., 2002). The sedimentary situation at Madjedbebe is similar to that at Nauwalabila but has been much less fully reported, making any serious evaluation of a proposed 50–60 ka human presence there difficult. The results of renewed excavations undertaken at Madjedbebe in 2012 may change matters once they are made public (see also below).

5. Discussion

Data presented in Table 1 show that humans reached Sahul by 47 ka. The difference from our 2003/2004 estimate of 43–45 ka is mainly a function of more precise radiocarbon date calibration at greater time depth than was possible when we wrote. That, combined with more effective sample pretreatment, allows the technique to generate accurate dates of 50–55 ka. With that in mind, we take the absence of reliable archaeological dates greater than 47 ka to indicate an outer bound for continental colonization. Contrary to claims made in the 1990s, and continuing in the recent literature (e.g. Oppenheimer, 2012; Cane, 2013; Hiscock, 2013; Smith, 2013), this is not a function of methodological constraints on radiocarbon dating. We discount claims for earlier age estimates based on luminescence and U-series analyses, not because of concerns about the dates themselves (although that issue certainly merits critical attention, as is the case with any dating technique), but because of uncertainties about the evidence of human presence and its relationship with the dates. On current evidence, an age estimate >50 ka from a new or already known site would be a definite outlier in the early continental chronology (more on this below).

5.1. Site distribution and process of colonization

Though still small, the sample of sites listed in Table 1 is sufficient to support speculative comment on the pattern and process of initial colonization. Analysts mostly agree that founding populations arrived in Sahul along Birdsell's (1977) northern and/or southern routes across Wallacea, via Sulawesi and/or Timor, respectively (Fig. 2). As argued elsewhere (O'Connell et al., 2010), travel east of Sunda probably involved hundreds of individuals and was almost certainly deliberate, if not always unidirectional. It required the use of well-made watercraft, some large enough to carry perhaps as many as a dozen people as well as several days' supply of food and water. Paddle-powered (possibly even sail-driven), such craft must have been capable of maintaining headway under a wide range of conditions, including moderately contrary currents.

Although the southern route is widely identified as the main avenue of access to Sahul, we think the northern route was more likely because of the consistent island inter-visibility and shorter voyaging distances it offered (Irwin, 1992; Allen and O'Connell,

Table 1

Earliest secure dates for archaeological sites probably occupied by anatomically modern humans in Wallacea, Sahul, and the Bismarck Archipelago. RS = rockshelter, OA = open air location, SC = solution cavity.

Region/Site	Location	Site type	Sample number	Earliest archaeological dates ($\times 10^3$ yr BP)			References
				^{14}C 1 σ range	^{14}C calibrated 1 σ range (median)	TL/OSL, U-series	
<i>Wallacea</i>							
Jerimalai	Timor	RS	Wk 17831	38.3 \pm 0.6	41.6–43.3 (42.5)		O'Connor, 2007
Lene Hara	Timor	RS	Wk 26405	38.2 \pm 0.6	41.6–43.3 (42.4)		O'Connor et al., 2010
Leang Timpuseng	Sulawesi	RS	LT 2.3			40.7 \pm 0.9	Aubert et al., 2014
<i>Sahul Far North</i>							
Bobongara	SE New Guinea	OA	Multiple samples			38–<60	Allen and O'Connell, 2014
Buang Merabak	New Ireland	RS	ANUA 15808–09	39.6 \pm 0.6	42.5–44.4 (43.5)		Leavesley and Chappell, 2004
Ivane -Vilakauv	SE New Guinea	OA	Wk 27072	42.0 \pm 1.6	43.1–49.1 (46.1)		Summerhayes et al., 2010
Ivane-South Kov	SE New Guinea	OA	Wk 23354	40.3 \pm 1.0	42.6–45.8 (44.2)		Summerhayes et al., 2010
Ivane-Airport Mound	SE New Guinea	OA	Wk 23356	39.8 \pm 0.9	42.3–45.3 (43.8)		Summerhayes et al., 2010
Ivane-AER Trench 2	SE New Guinea	OA	Wk 17901	35.1 \pm 0.7	38.4–41.2 (39.8)		Summerhayes et al., 2010
Kupona na Dari	New Britain	OA	OxL 1426			39.8 \pm 5.2	Torrence et al., 2004
Matenkupkum	New Ireland	RS	ANU 8179	35.4 \pm 0.4	39.1–41.0 (40.0)		Allen and Gosden, 1996
Yombon	New Britain	OA	BETA 62319	35.6 \pm 0.5	39.7–40.8 (40.2)		Pavrides and Gosden, 1994
<i>Sahul Mid-North</i>							
Carpenter's Gap	Kimberley	RS	ANUA 7616	40.6 \pm 0.8	43.0–45.7 (44.3)		Fifield et al., 2001
Djadjiling	Pilbara	RS	Wk 23313	35.8 \pm 0.5	39.2–41.6 (40.4)		Law et al., 2010
Ganga Mara ^a	Pilbara	RS	Wk 38973	40.4 \pm 0.9	43.5–45.0 (44.2)		Morse et al., 2014
GRE 8	Carpenteria	RS	Wk 11429	37.1 \pm 3.0	37.0–49.3 (43.1)		Slack, 2008; Slack et al., 2004
Jansz	Cape Range	RS	Wk 8919	35.2 \pm 0.5	38.8–40.9 (39.8)		Przywolnik, 2005; Smith, 2013
Nawarla Gabarnmang	Arnhem Land	RS	Wk 32126	42.9 \pm 1.5	44.2–49.6 (47.0)		David et al., 2013
Ngarrabullgan	Atherton	RS	ANUA 8806	35.5 \pm 0.7	38.7–41.5 (40.1)		David et al., 2007
Riwi	Kimberley	RS	ANUA 13005	41.3 \pm 1.0	43.1–46.9 (45.0)		Balme, 2000; Fifield et al., 2001
<i>Sahul Mid-South</i>							
Allen's Cave	Nullarbor Plain	SC	OxODAC 390			39.8 \pm 3.1	Murray and Roberts, 1997
Devil's Lair	SW Australia	RS	ANUA-11709 DL7	41.4 \pm 1.3	42.9–48.1 (45.4)		Turney et al., 2001a
						44.4 \pm 2.1	Turney et al., 2001a
Menindee	Darling Basin	OA	NZA 23736 LM10	41.5 \pm 1.6	42.9–49.0 (45.9)		Copper and Duncan, 2006
						43.1 \pm 3.7	Copper and Duncan, 2006
PACD H1	S Australia	OA	GNS NZA 34976	40.5 \pm 1.0	42.7–45.9 (44.3)		Walshe, 2012
Upper Swan	SW Australia	OA	SUA-1500	39.5 \pm 2.0	40.9–48.7 (44.8)		Pearce and Barbetti, 1981
Willandra	Murray Basin	OA	AA 4252 MG-1	38.1 \pm 1.1	40.7–44.5 (42.6)		Bowler and Price, 1998
						40.9 \pm 4.5	Olley et al., 2006
<i>Sahul Far South</i>							
Parmerpar Meethaner	N Tasmania	RS	Beta 68158 CAMS 10270	33.9 \pm 0.5	36.8–39.6 (38.2)		Cosgrove, 1995
Warreen	SW Tasmania	RS	Beta 42122A	34.8 \pm 0.5	38.4–40.6 (39.5)		Allen, 1996

^a Ganga Mara has recently been renamed Yurlu Kankala.

2008). In contrast, at 45–50 ka, when sea levels were 60–80 m below modern, the last leg on the southern route (Timor-Sahul) required a 200 km open-ocean crossing, twice the length of any of those on the northern route, and longer than any other voyage documented in this part of the world for the next 20,000 years (Allen and O'Connell, 2008; O'Connell et al., 2010). Moreover, return voyages, vital to the recruitment of additional colonists and the establishment of viable populations in Sahul, would have been very difficult, given the strong, south-flowing currents that prevail between Timor and the mainland (Wild, 1985:69; Irwin, 1992:28; Hautala et al. 2001).

Opinions differ concerning what happened next. Hypothetical scenarios vary on a continuum from rapid, continent-wide colonization, unimpeded by inter-regional differences in climate and environment (Birdsell, 1957), through long-term restriction to particular habitats as a function of cultural traditions that prevailed in colonizer homelands (Bowdler, 1977). (For models falling between these extremes see Hallam, 1977; Horton, 1981; White with O'Connell, 1982; Jones, 1989; Beaton, 1991; Webb and Rindos, 1997; Chappell, 2000; O'Connor and Veth, 2000; Bird et al., 2004; Bulbeck, 2007; Hiscock, 2008; Davidson, 2010, 2013; Smith, 2013).

Our own expectations about the colonization process are grounded in optimal foraging theory and further informed by recent work on modern hunter-gatherer economics. These have led us to develop several hypotheses about movement around and

across the continent as determined by variation in the costs and benefits of subsistence (O'Connell and Allen, 2012). (The same theoretical reasoning applies to movement through Wallacea [O'Connell et al., 2010]). We propose that major river basins contained the terrestrial habitats most attractive to human foragers, and that the vast interior arid zone, away from the coast and without perennial rivers and streams, was the least attractive. Some tropical forest settings may have been low ranked as well, due to the limited, often high-cost resource arrays they commonly offer to hunter-gatherers (e.g. Sillitoe, 2002; Cosgrove et al., 2007; cf. Roscoe, 2005). We propose that all other terrestrial habitats were of intermediate rank, scaled positively by the availability of water and negatively by the lower mean temperatures and correspondingly lower levels of productivity generally associated with higher latitudes and elevations.

We suggest that coasts marked by steeply sloping shorelines and rocky substrates were consistently attractive to foragers, despite the frequent, high amplitude changes in sea level characteristic of this period (Marine Isotope Stage 3 [MIS-3], 30–60 ka; Siddall et al., 2003), given the capacities of resident fauna (specifically shellfish) to adjust to those changes in real time (Beaton, 1995). On the other hand, the narrowness of the intertidal zone in these settings meant that potential prey were relatively few in number and hence susceptible to rapid depletion by humans. Broad, shallow coastal flats and estuaries were marked by greater

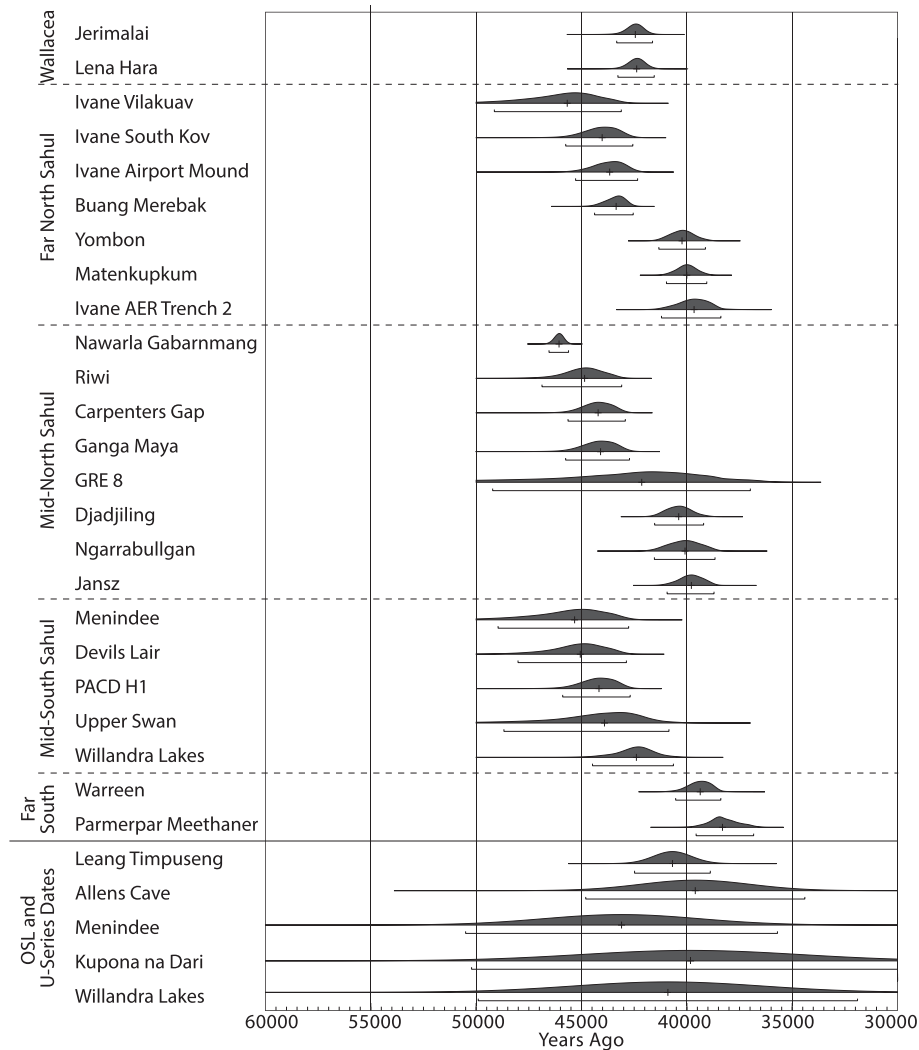


Fig. 1. Plot of calibrated radiocarbon dates and other radiometric age estimates for early human colonization of Sahul and nearby islands. Data from Table 1. Plus signs under each polygon indicate the central tendency; bars under those signs show two sigma limits bracketing that tendency. Tails show the absolute outer limits for each date or age estimate. Note that Ganga Mara has recently been renamed Yurlu Kankala.

resource diversities and higher prey densities and so should have been more appealing, just as they were historically (Birdsell, 1953). But their productivity may have been disrupted by those same MIS-3 sea level changes: the sedimentary substrates supporting that productivity may often have required centuries to reform in the wake of rapid rises and falls (Chappell, 1993). Data and opinion on this point are mixed (e.g. Beaton, 1985; Barham, 2000; Chappell, 2005; Bulbeck, 2007; Pope and Terrell, 2008:7–8; Manne and Veth, 2015; Ward et al. 2015), but we still consider it unlikely that these settings were as common, productive, and attractive to MIS-3 humans as they were from mid-Holocene times onward.

We argue that movement within and between coastal and terrestrial habitats was determined mainly by human depletion of high ranked prey. Declines in their availability made shifts to relatively rich but still unexploited patches elsewhere economically attractive. Given the generally low productivity of terrestrial Sahul habitats, a pattern exacerbated by the low temperature, precipitation and CO₂ values characteristic of Late Glacial times, resource depletion and subsequent human relocation may have been relatively rapid, even on a continental scale.

The distribution of early sites (Table 1, Fig. 2) is broadly consistent with these expectations. The oldest archaeological dates in

each of the three northernmost latitudinal segments (Ivane Vila-kauv [Highland New Guinea], Nawarla Gabarnmang [Arnhem Land], Devil's Lair and Menindee [SW and SE Australia, respectively]) are all in the range 45–47 ka, even though the latter two are several thousand kilometers from likely points of initial continental landfall in the northwest. The absence of similarly early dates from Tasmania reflects the fact that a dry land connection with the mainland Australia was not established until sometime after 43 ka (Lambeck and Chappell, 2001).

The distribution of early sites along the southwestern, western and northeastern margins of the continent generally fits with expectations about early reliance on coastal and riverine resources. Five of the 25 sites shown in Fig. 2 (Jansz [central W coast], Jerimalai, Lene Hara [Timor], Matenkupkum, Buang Merabak [New Ireland]) were within a few hundred meters of the shore when first occupied; one (Devil's Lair) was within a day's walk. Offshore profiles near all are steep, suggesting the presence of persistently attractive littoral habitats in the absence of human predation. Three localities are in the lower reaches of large river basins: Menindee and Willandra in the Murray-Darling, and the Swan River site (SW Australia). Seven sites are located in the upper reaches of smaller but still sizable river drainages: Carpenter's Gap and Riwi in the

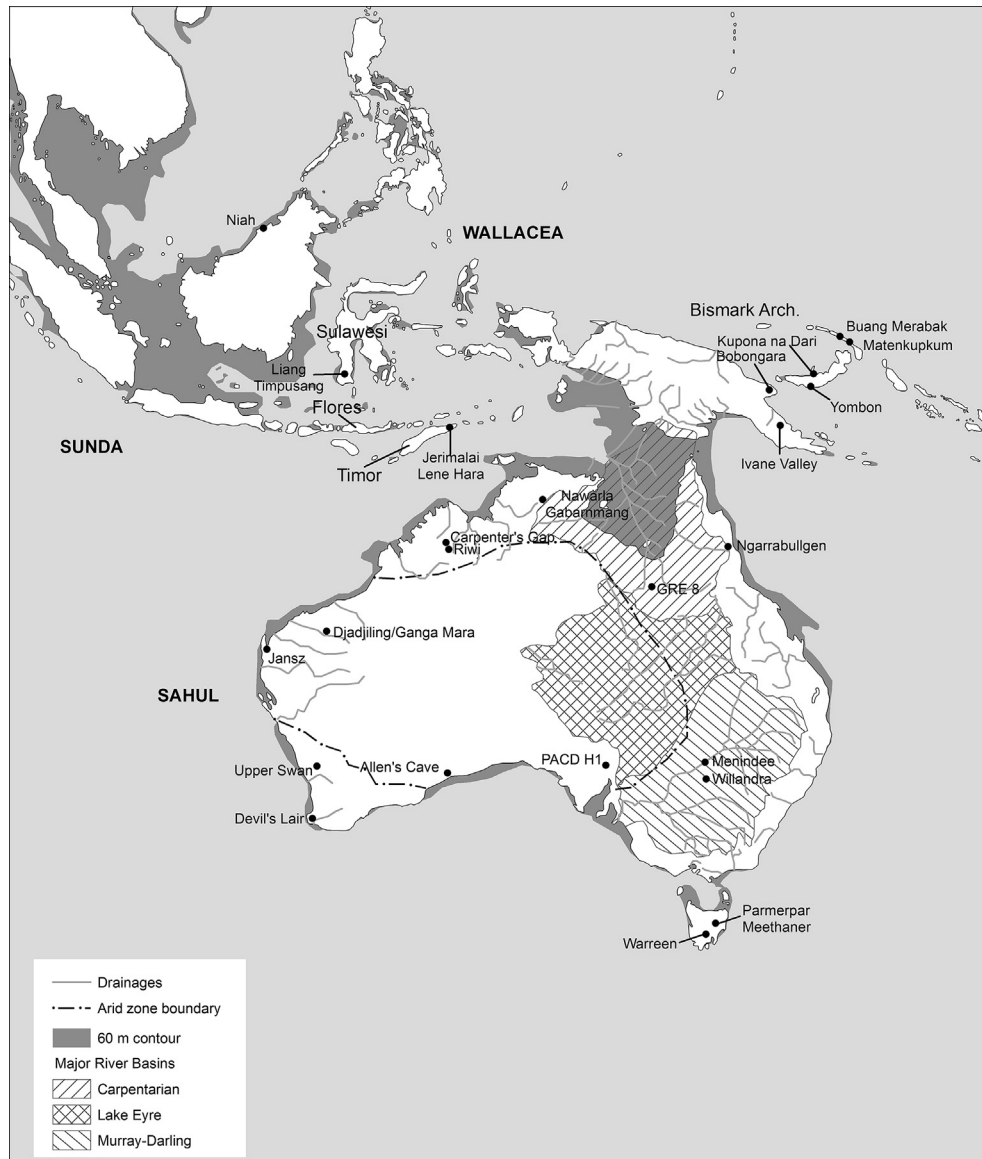


Fig. 2. Map showing locations of all sites listed in Table 1.

Fitzroy-Meda (Kimberley), Djadjiling and Ganga Mara in the Fortescue (Pilbara), GRE 8 and Ngarrabullgan in the Carpentarian, and Nawarla Gabarnmang in the Katherine (Arnhem Land). These data are all consistent with model-based expectations, as is the near-complete absence of early dates from the arid continental core away from sizable rivers or the coast. The slightly later occupation of Tasmania follows the same pattern: the earliest sites are all located in river valleys, adjacent to the rivers themselves.

Apparent exceptions to expectations include the several early sites in the Ivane Valley, the far southern arid zone site of Allen's Cave, and the lowland tropical forest site of Yombon (New Britain). Despite its altitude (2000 masl) and distance from the coast—at least three days' walk over rough terrain, the Ivane situation (all sites overlooking a pandanus swamp and close to the valley's rivers) offered early colonists an opportunity to exploit the alpine forest-grassland ecotone. This was a favorable habitat for New Guinea hunters historically, perhaps even more so in the distant past (e.g. Hope and Hope, 1976). Allen's Cave and Yombon are both situated in relatively unattractive settings — arid desert and

lowland rainforest, respectively. Still, Yombon was close to a major river and roughly a day's walk from the coast. The presence of a nearby toolstone source may have been an important attraction (Pavlidis and Gosden, 1994). Allen's Cave, located in an extensive limestone formation that has elsewhere yielded evidence of toolstone quarrying (Wright, 1971; Lowry and Jennings, 1974), may have been used for the same purpose, although published reports (e.g. Roberts et al., 1996) offer no evidence to support this suggestion. Alternatively, it may have been occupied for short periods of time by foragers drawn inland from the coast by occasional rain-related resource “flushes.”

Other distributional data that challenge our model include the low numbers of early sites so far reported from the Carpentarian-Eyre Basin-Murray-Darling region and their complete absence along the well-watered E Australian coast and hinterlands (compare the Pleistocene site map in Langley et al., 2011 with the Holocene map in Ulm, 2011). This might mean that post-depositional processes have covered or eroded evidence of early human presence, or that research has been insufficient to identify

it. The latter explanation seems unlikely for the coast and nearby hinterland in view of the development that large parts of that landscape have witnessed over the last century. It might well be that some of these areas were unoccupied early on, but we would find that surprising (Hughes et al., 2014; but see Bowdler, 2010).

Overall, the post-colonization pattern is now seen to differ from both the rapid, pan-continental and slow, culturally constrained, coastally oriented models proposed by Birdsell (1957) and Bowdler (1977), respectively. Continental-scale occupation was apparently rapid but selectively distributed across a range of favorable habitat types – prominent along some coasts and in certain especially attractive interior situations, but absent elsewhere for many millennia. The archaeological “footprint” measured by site numbers, refuse deposition rates and radiocarbon date counts is also light, not only for the 6000–7000 years after landing, but from then on through the terminal Pleistocene, nearly thirty thousand years later (e.g. Lourandos, 1980; Beaton, 1985; Lourandos and Ross, 1994; O'Connell and Allen, 2012; Williams, 2013). The obvious implication is that human population numbers remained very low throughout this time, perhaps in the tens of thousands continent-wide, roughly two orders of magnitude below the several million range estimated for Australia-New Guinea combined at European contact (Brookfield with Hart, 1971; Williams, 2013). As suggested elsewhere (O'Connell and Allen, 2012), low glacial-era environmental productivity produced by low temperature, precipitation and CO₂ values, combined with high levels of relatively short-term climatic instability may have been responsible.

5.2. Habitat modification and megafaunal extinctions

Our estimated 47 ka human arrival threshold matches more or less closely with dated evidence said to mark significant colonizer impacts on Sahul fauna and flora. These purportedly included the widespread displacement of fire-sensitive with fire-tolerant flora, sub-continental scale reductions in tree cover, a consequent decline in evapotranspiration rates leading to drastic diminution in the strength of the summer monsoon, and the rapid, Australia-wide elimination of >60 species of large-bodied marsupials, birds and reptiles, all in the period 45–50 ka (e.g. Roberts et al., 2001; Miller et al., 2005; Gillespie et al., 2006; Brook et al., 2007; Turney et al., 2008; Prideaux et al., 2010; Roberts and Brook, 2010; Rule et al., 2012; Lopes de Santos et al., 2013). Changes in flora are said to have been brought about through human use of fire as a foraging tool and/or by the elimination of large animal consumers. Large animal extinctions are attributed to some combination of human predation and fire-induced vegetation change. Arguments in favor of these propositions differ in various ways, but human interference is the catalytic element in all of them. Non-anthropogenic climate change is taken to have been limited in this time frame, and hence irrelevant to any changes in biota.

Counter-arguments developed over the last decade hold that the ecological changes noted above were likely to have been mainly climate-driven. Shifts in flora and the disappearance of megafauna are seen to have been connected with a general trend from 350 to 400 ka onward toward increased continental aridity and progressively lower glacial-period temperatures and atmospheric CO₂ values (e.g. Kershaw et al., 2003; Price et al., 2011). Proponents of this view observe that by the time humans arrived, only 8–14 large-bodied taxa, from a total of 88 or more now-extinct Pleistocene forms across New Guinea and Australia combined, were definitely still extant (Wroe and Field, 2006; Wroe et al., 2013). Up to eight of these may have persisted until as recently as 28 ka (Trueman et al., 2005; Field et al., 2008; Fillios et al., 2010; cf. Grün et al., 2010). Changes in vegetation and related shifts in fire frequency over the period 70–10 ka, monitored via pollen and

charcoal spectra, correlate with high-amplitude, millennial scale Dansgaard-Oeschger temperature cycles and with extremely cold, centennial-scale Heinrich Events (Mooney et al., 2011). These phenomena are well marked in high latitude ice cores (e.g. Weninger and Jöris, 2008) and clearly evident in tropical and southern temperate zone proxies, including some from Sahul (e.g. Burns et al., 2003; Turney et al., 2004; Brown et al., 2007; Dürkop et al., 2008; Hunt et al., 2012; Denniston et al., 2013). Their effect on Sahul megafauna is still unresolved, but a causal link with extinctions cannot be dismissed (For additional case studies and discussion in support of this line of argument see Kershaw et al., 2003; Webb, 2008; Cosgrove et al., 2010; Faith and O'Connell, 2011; Cohen et al., 2012; Kaal et al., 2014; Murphy et al., 2012; Sakaguchi et al., 2013; Habeck-Fardy and Nanson, 2014; Lima-Ribeiro and Dinez-Filho, 2014).

While there is no direct evidence of human predation on now-extinct large animals anywhere in Sahul (no kill sites, no stone tool cut-marked or impact-scarred bones), we would be surprised if human colonizers failed to take megafauna whenever possible. The question is whether low human numbers and patchy distribution across the continent would have allowed them to drive 8–14 taxa (let alone 60–80) to extinction within one or two millennia in the absence of other contributing factors. Simulation studies claimed to support this possibility are based on unrealistically high estimates of post-colonization human population growth rates. At the 1–2.5% per annum figure posited by Brook and Bowman (2004), for example, a founding group of 500 grows to several million in less than two millennia. Archaeological data summarized above show that human populations remained well below this level until the middle Holocene. Parallel arguments (e.g. Brook and Johnson, 2006) indicating that low kill rates involving sub-adult individuals might have led to rapid demographic collapse yet leave little archaeological evidence are theoretically plausible, but limited by the fact that they have so far considered only the largest, hence slowest reproducing Sahul taxon – *Diprotodon optatum*. Smaller-bodied taxa (e.g. *Protemnodon*, *Sthenurus*, both present when humans arrived) were probably marked by earlier ages at maturity and higher reproductive rates (Charnov, 1993; Zou et al., 2013), and so were far less vulnerable on this count. (Note too that, simulation results notwithstanding, *Diprotodon* is one of several megafaunal taxa that may have persisted for many millennia after human arrival [Field et al., 2008]).

Assertions about the environmental impact of early anthropogenic landscape-scale fire are based mainly on two data sets. One, from the Lake Eyre Basin (south central Australia), includes stable isotope readings on eggshells from two flightless birds, emu and larger, now-extinct *Genyornis*. These are read to indicate an abrupt shift, dated 45–50 ka, from tree/shrub savannah to desert scrub, a transition characterized as a “massive ecosystem collapse,” entirely attributable to the introduction of a human-mediated fire regime (Miller et al., 2005, 2007). The other body of evidence includes pollen, charcoal and other material contained in long sediment cores extracted from Lynch's Crater, a volcanic caldera in NE Australia. These data point to an increase in fire frequency and a related shift from mixed rainforest to drier sclerophyll vegetation beginning ca. 45 ka. Both are said to have been caused either by the establishment of an anthropogenic fire regime (Kershaw, 1986; Turney et al., 2001b) or by human elimination of large-bodied herbivores, the latter leading to an increase in fuel loads that in turn promoted more frequent fires (Rule et al., 2012). Climate change is explicitly dismissed as a contributing factor in both cases.

The environmental changes reported in these two situations appear to have been significant; the questions are whether they were as extreme as suggested, whether they coincided with human arrival, and whether they were the result of human interference. As

noted above, a number of recent studies make strong arguments in favor of climate as the primary catalyst, with humans assigned at most a minor contributing role (e.g. Mooney et al., 2011; Bowman et al., 2012; Bird et al., 2013). The idea that changes in Eyre Basin vegetation were “abrupt” or solely related to human action is contradicted by reanalysis of some of the same stable isotope and geomorphological data cited in support of that interpretation, showing instead a continuous trend toward drier conditions beginning about 80 ka, well in advance of human presence (Notaro et al., 2011; Cohen et al., 2012; Murphy et al., 2012; Habeck-Fardy and Nanson, 2014). The Lynch's Crater data are increasingly characterized as unreliable markers of human action, given the difficulty of distinguishing possible anthropogenic effects from those attributable to climate in this setting (Lynch et al., 2007; Bliege Bird et al., 2008; Murphy and Bowman, 2012; Bird et al., 2013).

Assumptions about the scale of early human impact are crucial here. Advocates of strictly anthropogenic causality assume that human-controlled fires had a much greater effect on vegetation than those generated by non-anthropogenic ignition sources, specifically lightning. This discounts the evidence that fire has been a major ecological force all across Sahul for millions of years (e.g. Lynch et al., 2007). It also assumes that initial human population densities and distributions were similar to those responsible for the maintenance of anthropogenic fire regimes reported historically (e.g. Gammage, 2011). And it ignores ethnographic observations showing that human-mediated landscape-scale fires are orders of magnitude smaller in extent and ecologically less disruptive than the larger of those generated by lightning. As Bliege Bird and colleagues (2012) have observed, human-controlled fire in low population settings buffers the impact of non-anthropogenic fire – it does not exacerbate or exceed it as a disruptive force. This observation is based on the use of fire during the recent Aboriginal reoccupation of parts of the Western Desert, and for that reason seems likely to apply with similar, if not equal force to the early stages of Sahul colonization.

The effect of human arrival on Sahul flora and fauna remains controversial. Some impact seems likely in principle, but the case for massive, anthropogenic fire-related ecosystem collapse and catastrophic megafaunal overkill is far less clear-cut. Ironically, a secure estimate for human colonization ca. 47 ka offers no compelling support for these propositions (cf. Roberts et al., 2001). We agree with those who see climate as the primary determinant of ecological change in Late Pleistocene Sahul, with humans having a significant impact only from early/mid Holocene times onward, when their populations achieved densities and distributions similar to those observed at the time of European contact (Williams, 2013).

5.3. Sahul and Late Pleistocene human dispersals beyond E Africa/SW Asia

The finding that humans arrived in Sahul ca. 47 ka also speaks to current arguments about the Upper Pleistocene spread of anatomically modern humans (AMH) beyond Africa. Key questions concern the number and timing of such movement(s), the identities of the populations involved, and the ecological and evolutionary forces driving the process. Discussion is complicated by limited and controversial hominin fossil and archaeological data, by uncertainties about the phylogenetic significance of the fossil evidence, by the complexities of modeling and dating a rapidly growing genomic database, and by the difficulties of linking archaeological evidence with populations defined on biological grounds (Davidson, 2014). Detailed review is well beyond us here, but some general observations on the timing and population identity issues are in order.

Current consensus favors a sub-Saharan African origin of AMH in the late Middle Pleistocene (Klein, 2009). Opinions about later movement beyond Africa are divided between two alternatives: 1) a Late Dispersal Model (LDM), initially into SW Asia at about 60 ka, then accelerating across Eurasia and into Sahul beginning about 50 ka; 2) an Early Dispersal Model (EDM) involving an initial move across S Asia as early as the Last Interglacial (100–120 ka) followed by a later spread into N Eurasia, again after 50 ka.

The LDM finds strong support from genetic data (e.g. Wollstein et al., 2010; Gronau et al., 2012; Hernandez et al., 2011; Poznik et al., 2013). The pattern is particularly clear from analyses of modern and fossil human mitochondrial (mt) DNA, still the best characterized locus for dating human migrations (e.g. Endicott et al., 2009; Soares et al., 2009, 2012; Behar et al., 2012; Fernandes et al., 2012; Henn et al., 2012; Fu et al., 2013b; Mellars et al., 2013b; Rito et al., 2013). These studies confirm and elaborate the observation, initially made by Cann et al. (1987), that all modern non-African populations trace the mitochondrial component of their genomes to an African source, now called the L3 lineage. Groups representing this lineage are thought to have spread from East Africa to SW Asia roughly 70–60 ka. Consideration of relevant climatic data suggests that this movement may have taken place close to 60 ka, or perhaps shortly after, coincident with the warmer temperatures and increased precipitation values associated with the onset of MIS-3 (Eriksson et al., 2012; Boivin et al., 2013; Parton et al., 2013). Preceding MIS-4 (70–60 ka) was marked by extreme aridity all across northern Africa and Arabia, inhibiting any move into SW Asia until conditions improved. If L3-related populations did venture beyond Africa during MIS-4, their distributions are likely to have been restricted to a few widely scattered, relatively favorable locations, including the coastal margins of the Arabian Peninsula and the riverine corridor exposed by sea level falls in what is now the Persian Gulf (Rose, 2010; Fernandes et al., 2012; Mellars et al., 2013a).

Once they reached SW Asia, L3-related populations apparently remained in place for several thousand years – long enough to allow introgression with local Neandertals, an inference based on nuclear DNA (Green et al., 2010; Sankararaman et al., 2012; Fu et al., 2014; see also Hershkovitz et al. 2015), and the subsequent development of three mitochondrial daughter lineages, N, ^NR, and possibly M (Atkinson et al., 2009; Fernandes et al., 2012; Mellars et al., 2013b). Archaeological, fossil and genetic data indicate movement beyond SW Asia beginning ca. 50 ka, reaching east to the exposed Sunda Shelf no later than ca. 48 ka (Barker et al., 2007; Hudjashov et al., 2007; Atkinson et al., 2008; Demeter et al., 2012) and north into Eurasia at about the same time or slightly later (Hoffecker, 2009; Richter et al., 2009; Henn et al., 2012; Fu et al., 2014). Rapid transit across S Asia to Sahul is indicated by the absence of geographic hierarchy in L3-derived daughter lineages along this arc (e.g. Macaulay et al., 2005; Friedlaender et al., 2007; Hudjashov et al., 2007; Soares et al., 2009; van Holst Pellekaan, 2013). Macro-haplogroups M, N and ^NR are all represented in Sahul; all early Sahul-specific lineages within these haplogroups are derived directly from SW Asian sources rather than S Asian intermediates, implying eastward movement faster than the mtDNA mutation rate. (Haplogroup M may represent a partial exception regarding source: S vs. SW Asia [see Mellars et al., 2013b for discussion]). Introgression with archaic Denisovans occurred at some point(s) in this transit, perhaps in SE Asia (Reich et al., 2011; Rasmussen et al., 2011; cf. Cooper and Stringer, 2013).

Our revised assessment of Sahul colonization dates is consistent with this scenario. It seems increasingly likely that the initial occupation of Pleistocene Australia-New Guinea was part of a rapid, Eurasia-wide expansion of AMH beyond SW Asia beginning about

50 ka (Henn et al., 2012). One might question the validity of the correlation, in that 1) some estimates of the mitochondrial mutation rate have employed a 45–50 ka Sahul colonization date as an analytic benchmark (e.g. Endicott et al., 2009), introducing potential circularity, and 2) recent studies of the nuclear genome (e.g. Scally and Durbin, 2012) have suggested a significantly slower mutation rate, which would push autosomal estimates of the exit from Africa much further back in time. However, subsequent analyses of mtDNA from ten radiocarbon dated European and E Asian AMH fossils (Fu et al., 2014) independently indicate a rate consistent with those calibrated on a 45–50 ka Sahul arrival time. The age for Q, the oldest known autochthonous N Sahul mitochondrial haplogroup, calculated on this fossil-derived mutation rate, is estimated at 42 ka (95% CI: 30–54 ka; Fu et al., 2013b: Table 3), which fits, within the limits of these methodologies, with both our revised Sahul archaeological chronology and with the Late Dispersal Model.

Arguments in favor of an earlier Upper Pleistocene dispersal rely on various combinations of human fossil, archaeological and genetic evidence (e.g. Oppenheimer, 2012). Fossil-based scenarios highlight the presence of AMH or similar morphologies in pre-60 ka contexts in E and SE Asia (e.g. Shen et al., 2002; Westaway et al., 2007; Liu et al., 2010; Mijares et al., 2010). All are plausible, but open to challenge on the reliability of fossil identifications as AMH, the validity of proposed dates, or their associations with the fossils in question. Archaeological models are based on claims for African-derived Middle Paleolithic or Middle Stone Age lithic assemblages and reduction sequences dated 120–70 ka in Arabia and S Asia (e.g. Foley and Lahr, 1997; Petraglia et al., 2010, 2012; Armitage et al., 2012; Clarkson et al., 2012; Dennell and Petraglia, 2012; cf. Mellars et al., 2013a). The contention that these assemblages were produced by anatomically modern humans is also plausible, but not well supported empirically. Archaic human populations are known to have produced similar industries at the same time elsewhere (e.g. Shea, 2003).

Advocates of the EDM favor the much slower mutation rate reported by Scally and Durbin (2012) and the extended time scale for AMH dispersal it implies. They also point to nuclear DNA data indicating that lineages ancestral to Sahul populations separated at an early date from those leading to European and E Asian groups. Pre-60 ka colonization of Sahul is seen by some to be implied (e.g. Ghiretto et al., 2011; Reyes-Centano et al., 2014). However, other autosomal studies, while emphasizing a complex, multi-migration scenario for E Asia and Sahul (McEvoy et al., 2011; Rasmussen et al., 2011), still date the initial post-L3 divergence events to 70–60 ka, inconsistent with an EDM. The recent analysis of ancient AMH remains from Europe and E Asia (Fu et al., 2014) also challenges the “slow” model as it pertains to nuclear elements of the genome. Debate about mutation rates nevertheless continues (Segural et al., 2014). Even if an early separation of ancestral Sahul from European and E Asian lineages is confirmed, as it might well be (Fu et al., 2013a), its precise date remains uncertain and nothing about the timing of Sahul colonization necessarily follows.

Although the case for one or more AMH dispersals beyond SW Asia 120–70 ka is far from established, we do not necessarily discount the idea. The questions addressed here are whether the Sahul archaeological record supports it, and if it does whether that somehow falsifies a 50 ka dispersal event and its role in Sahul colonization. We think the answer to both questions is no. The LDM is increasingly well warranted on genetic, fossil and archaeological grounds; Sahul archaeological and mtDNA data provide strong evidence for it. There may have been earlier dispersals across S Asia, one or more of which reached Sahul. Confirmation of a pre-50 ka presence at Madjedbebe would help make that case. But in the

absence of more compelling evidence than is available at present, we are skeptical about these possibilities.

Dedicated search in the 25 years since the early dates from Madjedbebe were first reported has yet to produce a similar, analytically verified finding from another site, a situation that can no longer be attributed to the methodological limits of radiocarbon dating. If a 50–60 ka date for Madjedbebe were confirmed, it would be as we said a definite outlier, separated by up to 13,000 years from the next earliest indication of human presence in Sahul. The notion that it marked the start of continuous, continental-scale occupation by anatomically modern humans, or for that matter by an archaic human population, would be difficult to credit (cf. Cooper and Stringer, 2013). Any relationship with the populations that arrived after 48 ka, the likely ancestors of most of the Sahul indigenes encountered at European contact, would have been limited at best.

5.4. Looking ahead

Several issues involving chronology will continue to be important going forward. First, while it seems increasingly likely that ancestors of modern Sahul indigenes first arrived on the continent ca. 47 ka, the possibility of an earlier human presence cannot be completely dismissed. Archeological evidence on chronology and genomic data on the identities of the populations involved will require careful, comprehensive evaluation. Greater cross-disciplinary collaboration with geneticists will be crucial. Similarly, while the complexity of Late Pleistocene Sahul climate change and its impact on habitat and human populations is increasingly apparent, the details of those changes and their chronologies must be understood with much greater precision at regional scales than is currently the case. Close interaction on the part of archaeologists and earth scientists will be essential here. Finally, more effort must be directed at integrating information on the human colonization of Sahul with the broader picture of human experience across the Eastern Hemisphere in the Late Pleistocene. Geneticists are providing important insights on this issue, but archaeologists must continue to be seriously engaged. The key question about what causes and facilitates the one or more ex-African expansions must also be more seriously engaged, preferably in potentially testable form.

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References

- Allen, J., 1989. When did humans first colonize Australia? *Search* 20, 149–154.
- Allen, J., 1996. Warreen cave. In: Allen, J. (Ed.), *Report of the Southern Forests Archaeological Project, vol. 1: Site Descriptions, Stratigraphies and Chronologies*. Archaeology Publications, School of Archaeology, La Trobe University, Bundoora, pp. 135–167.
- Allen, J., Gosden, C., 1996. Spheres of interaction and integration: modelling the culture history of the Bismarck Archipelago. In: Davidson, J.M., Irwin, G., Leach, B.F., Pawley, A., Brown, O. (Eds.), *Oceanic Culture History: Essays in Honour of Roger Green*. New Zealand Journal of Archaeology Special Publication, pp. 183–197.
- Allen, J., O'Connell, J.F., 2003. The long and the short of it: archaeological approaches to determining when humans first colonised Australia and New Guinea. *Aust. Archaeol.* 57, 5–19.
- Allen, J., O'Connell, J.F., 2008. Getting from Sunda to Sahul. In: Clark, G., Leach, B.F., O'Connor, S. (Eds.), *Islands of Inquiry: Colonisation, Seafaring and the Archaeology of Maritime Landscapes, Terra Australis* 29. ANU E-Press, Canberra, pp. 31–46.

- Allen, J., O'Connell, J.F., 2014. Both half right: updating the evidence for dating first human arrivals in Sahul. *Aust. Archaeol.* 79, 86–108.
- Armitage, S.J., Jasim, S.A., Marks, A.E., Parker, A.G., Usik, V.I., Uerpmann, H.-P., 2012. The Southern Route "Out of Africa": evidence for an early expansion of modern humans into Arabia. *Science* 331, 453–456.
- Atkinson, Q.D., Gray, R.D., Drummond, A.J., 2008. mtDNA variation predicts population size in humans and reveals a major Southern Asian chapter in human prehistory. *Mol. Biol. Evol.* 25, 468–474.
- Atkinson, Q.D., Gray, R.D., Drummond, A.J., 2009. Bayesian coalescent inference of major human mitochondrial DNA haplogroup expansions in Africa. *Phil. Trans. Roy. Soc. B* 276, 367–373.
- Aubert, M., Brumm, A., Ramli, M., Sutikna, T., Saptomo, E.W., Hakim, B., Morwood, M.J., van den Berg, G.D., Kinsley, L., Dosseto, A., 2014. Pleistocene cave art from Sulawesi, Indonesia. *Nature* 514, 223–227.
- Balme, J., 2000. Excavations revealing 40,000 years of occupation at Mimbi Caves, south central Kimberley, Western Australia. *Aust. Archaeol.* 51, 1–5.
- Barham, A.J., 2000. Late Holocene societies in the northern Torres Strait Islands. In: O'Connor, S., Veth, P. (Eds.), *East of Wallace's Line: Studies of Past and Present Maritime Cultures of the Indo-Pacific Region*. Balkema, Rotterdam, pp. 223–314.
- Barker, G., Barton, H., Bird, M., et al., 2007. The 'human revolution' in lowland tropical Southeast Asia: the antiquity and behavior of anatomically modern humans at Niah Cave (Sarawak, Borneo). *J. Hum. Evol.* 52, 243–261.
- Beaton, J.M., 1985. Evidence for a coastal occupation time-lag at Princess Charlotte Bay (north Queensland) and implications for coastal colonization and population growth theories for Aboriginal Australia. *Archaeol. Ocean.* 20, 1–20.
- Beaton, J.M., 1991. Colonizing continents: some problems from Australia and the Americas. In: Dillehay, T.D., Meltzer, D.J. (Eds.), *The First Americans: Search and Research*. CRC Press, Boca Raton, pp. 209–230.
- Beaton, J.M., 1995. The transition on the coastal fringe of Greater Australia. *Antiquity* 69, 709–806.
- Behar, D.M., van Oven, M., Rosset, S., Metspalu, M., Loogvali, E.-L., Silva, N.M., Kivisild, T., Torroni, A., Villems, R., 2012. A 'Copernican' reassessment of the human mitochondrial DNA tree from its root. *Am. J. Hum. Gen.* 90, 675–684.
- Bird, M.I., Ayliffe, L.K., Fifield, L.K., Cresswell, R., Turney, C., 1999. Radiocarbon dating of "old" charcoal using a wet oxidation, stepped-combustion procedure. *Radiocarbon* 41, 127–140.
- Bird, M.I., Hope, G., Taylor, D., 2004. Populating PEP II: the dispersal of humans and agriculture through Austral-Asia and Oceania. *Quat. Int.* 118–119, 145–163.
- Bird, M.I., Hutley, L.B., Lawes, M.J., Lloyd, J.G., Ridd, P.V., Roberts, R.G., Ulm, S., Wurster, C.M., 2013. Humans, megafauna and environmental change in tropical Australia. *J. Quat. Sci.* 28, 439–452.
- Bird, M.I., Turney, C.S.M., Fifield, L.K., Jones, R., Ayliffe, L., Palmer, A., Cresswell, R., Robertson, S., 2002. Radiocarbon analysis of the early archaeological site of Nauwalabila 1, Arnhem Land, Australia: implications for sample suitability and stratigraphic integrity. *Quat. Sci. Rev.* 21, 1061–1075.
- Birdsell, J.B., 1953. Some environmental and cultural factors influencing the structuring of Australian Aboriginal populations. *Am. Nat.* 87, 171–207.
- Birdsell, J.B., 1957. Some population problems involving Pleistocene man. *Cold Spr. Harb. Symp. Quant. Biol.* 22, 47–69.
- Birdsell, J.B., 1977. The recalibration of a paradigm for the first peopling of Greater Australia. In: Allen, J., Golson, J., Jones, R. (Eds.), *Sunda and Sahul: Prehistoric Studies in Southeast Asia, Melanesia and Australia*. Academic Press, London, pp. 113–167.
- Bliege Bird, R., Bird, D.W., Codding, B.F., Parker, C.H., Jones, J.H., 2008. The 'fire stick' farming hypothesis: Australian Aboriginal foraging strategies, biodiversity and anthropogenic fire mosaics. *Proc. Natl. Acad. Sci. U. S. A.* 105, 14796–14801.
- Bliege Bird, R., Codding, B.F., Kauhanen, P.G., Bird, D.W., 2012. Aboriginal hunting buffers climate-driven fire-size variability in Australia's spinifex grasslands. *Proc. Natl. Acad. Sci. U. S. A.* 109, 10287–10292.
- Boivin, N., Fuller, D.Q., Dennell, R., Allaby, R., Petraglia, M.D., 2013. Human dispersal across diverse environments of Asia during the Upper Pleistocene. *Quat. Int.* 300, 32–47.
- Bowdler, S., 1977. The coastal colonisation of Australia. In: Allen, J., Golson, J., Jones, R. (Eds.), *Sunda and Sahul: Prehistoric Studies in Southeast Asia, Melanesia and Australia*. Academic Press, London, pp. 205–245.
- Bowdler, S., 1990. 50,000 year-old site in Australia – is it really that old? *Aust. Archaeol.* 31, 93.
- Bowdler, S., 2010. The empty coast: conditions for human occupation in southeast Australia during the late Pleistocene. In: Haberle, S., Stevenson, J., Prebble, M. (Eds.), *Altered Ecologies: Fire, Climate and Human Influence on Terrestrial Landscapes*, *Terra Australis* 32. ANU E Press, Canberra, pp. 177–185.
- Bowler, J.M., Price, D.M., 1998. Luminescence dates and stratigraphic analyses at Lake Mungo, review and new perspectives. *Archaeol. Ocean.* 33, 156–168.
- Bowman, D.M.J.S., Murphy, B.P., Burrows, G.E., Crisp, M.D., 2012. Fire regimes and the evolution of the Australian biota. In: Williams, R.J., Gill, A.M., Bradstock, R.A. (Eds.), *Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World*. CSIRO Publishing, Collingwood (VIC), pp. 27–48.
- Bronk Ramsey, C., Staff, R.A., Bryant, C.L., et al., 2012. A complete terrestrial radiocarbon record for 11.2 to 52.8 ka B.P. *Science* 338, 370–374.
- Brook, B.W., Bowman, D.M.J.S., 2004. The uncertain blitzkrieg of Pleistocene megafauna. *J. Biogeogr.* 31, 517–523.
- Brook, B.W., Bowman, D.M.J.S., Burney, D.A., et al., 2007. Would the Australian megafauna have become extinct if humans had never colonised the continent? Comments on "A review of the evidence for a human role in the extinction of Australian megafauna and an alternative explanation" by S. Wroe and J. Field. *Quat. Sci. Rev.* 26, 560–564.
- Brook, B.W., Johnson, C.N., 2006. Selective hunting of juveniles as a cause of the imperceptible overkill of the Australian Pleistocene megafauna. *Alcheringa Spec. Iss.* 1, 39–48.
- Brookfield, H.C., Hart, D., 1971. *Melanesia: Geographical Interpretation of an Island World*. Methuen, London.
- Brown, E.T., Johnson, T.C., Schultz, C.A., Cohen, A.S., King, J.W., 2007. Abrupt change in tropical African climate linked to bipolar seesaw over the past 55,000 years. *Geophys. Res. Lett.* 34, L20702.
- Bulbeck, D., 2007. Where the river meets the sea: a parsimonious model for Homo sapiens colonization of the Indian Ocean and Sahul. *Curr. Anthropol.* 48, 315–321.
- Burns, S.J., Fleitmann, D., Matter, A., Kramers, J., Al-Subbar, A.A., 2003. Indian Ocean climate and an absolute chronology over Dansgaard/Oeschger Events 9 to 13. *Science* 301, 1365–1367.
- Cane, S., 2013. *First Footprints: the Epic Story of the First Australians*. Allen & Unwin, Sydney.
- Cann, R., Stoneking, M., Wilson, A.C., 1987. Mitochondrial DNA and human evolution. *Nature* 325, 31–36.
- Chappell, J., 1993. Late Pleistocene coasts and human migrations in the Austral region. In: Spriggs, M., Yen, D.E., Ambrose, W., Jones, R., Thorne, A.G., Andrews, A. (Eds.), *A Community of Culture: the People and Prehistory of the Pacific*, *Occasional Papers in Prehistory*, No. 21. Department of Prehistory, Research School of Pacific Studies, Australian National University, Canberra, pp. 43–48.
- Chappell, J., 2000. Pleistocene seedbeds of western Pacific maritime cultures and the importance of chronology. In: O'Connor, S., Veth, P. (Eds.), *East of Wallace's Line: Studies of Past and Present Maritime Cultures of the Indo-Pacific Region*. Balkema, Rotterdam, pp. 77–98.
- Chappell, J., 2005. Geographic changes of coastal lowlands in the Papuan past. In: Pauley, A., Attenborough, R., Golson, J., Hide, R. (Eds.), *Papuan Pasts: Cultural, Linguistic and Biological Histories of Papuan-speaking Peoples*. Pacific Linguistics, Research School of Pacific and Asian Studies, Australian National University, Canberra, pp. 525–539.
- Chappell, J., Magee, J., Head, J., 1996. Beyond the radiocarbon limit in Australian archaeology and Quaternary research. *Antiquity* 70, 543–552.
- Charnov, E.L., 1993. *Life History Invariants: Some Explorations of Symmetry in Evolutionary Ecology*. Oxford University Press, Oxford.
- Clarkson, C., Harris, C., Jones, S., 2012. Continuity and change in the lithic industries of the Jurreru Valley, India, before and after the Toba eruption. *Quat. Intl* 258, 165–179.
- Cohen, T.J., Nanson, G.C., Jansen, J.D., Jones, B.G., Jacobs, Z., Larson, J.R., May, J.-H., Treble, P., Price, D.M., Smith, A.M., 2012. Late Quaternary megalakes fed by the northern and southern river systems of central Australia: varying moisture sources and increased continental aridity. *Palaeogeogr. Palaeoclim. Palaeoecol.* 356–357, 89–108.
- Cooper, A., Stringer, C.B., 2013. Did the Denisovans cross Wallace's Line? *Science* 342, 321–323.
- Cosgrove, R., 1995. Late Pleistocene behavioural variation and time trends: the case from Tasmania. *Archaeol. Ocean.* 30, 83–104.
- Cosgrove, R., Field, J., Ferrier, A., 2007. The archaeology of Australia's tropical rainforests. *Palaeogeogr. Palaeoclim. Palaeoecol.* 251, 150–173.
- Cosgrove, R., Field, J., Garvey, J., Brenner-Coltrain, J., Goede, A., Charles, B., Wroe, S., Pike-Tay, A., Grün, R., Aubert, M., Lees, W., O'Connell, J., 2010. Overdone overkill – the archaeological perspective on Tasmanian megafaunal extinctions. *J. Archaeol. Sci.* 37, 2486–2503.
- Copper, M.L., Duncan, J., 2006. Late Glacial megafaunal death assemblage and early human occupation at Lake Menindee, southeastern Australia. *Quat. Res.* 66, 332–341.
- David, B., Barker, B., Petchev, F., Delannoy, J.-J., Geneste, J.-M., Rowe, C., Eccleston, M., Lamb, L., Whar, R., 2013. A 28,000 year old excavated painted rock from Nawarla Gabarnmang, northern Australia. *J. Archaeol. Sci.* 40, 2493–2501.
- David, B., Roberts, R.G., Magee, J., Mialanes, J., Turney, C., Bird, M., White, C., Fifield, L.K., Tibby, J., 2007. Sediment mixing at Nonda Rock: investigations of stratigraphic integrity at an early archaeological site in northern Australia and implications for the human colonisation of the continent. *J. Quat. Sci.* 22, 449–479.
- Davidson, I., 2010. The colonization of Australia and its adjacent islands and the evolution of modern cognition. *Curr. Anthropol.* 51, S177–S189.
- Davidson, I., 2013. Peopling the last new worlds: the first colonisation of Sahul and the Americas. *Quat. Int.* 285, 1–29.
- Davidson, I., 2014. It's the thought that counts: unpacking the package of behavior of the first people of Australia and its adjacent islands. In: Dennell, R., Porr, M. (Eds.), *Southern Asia, Australia, and the Search for Human Origins*. Cambridge University Press, Cambridge, pp. 243–256.
- Demeter, F., Shackelford, L.L., Bacon, A.M., et al., 2012. Anatomically modern human in Southeast Asia (Laos) by 46 ka. *Proc. Natl. Acad. Sci. U. S. A.* 109, 14375–14380.
- Dennell, R., Petraglia, M., 2012. The dispersal of Homo sapiens across southern Asia: how early, how often, how complex? *Quat. Sci. Rev.* 47, 15–22.
- Denniston, R.F., Wyroll, K.H., Asmerom, Y., Polyak, V.J., Humphreys, W.F., Cugley, J., Woods, D., LaPointe, Z., Peota, J., Greaves, E., 2013. North Atlantic forcing of

- millennial-scale Indo-Australian monsoon dynamics during the Last Glacial period. *Quat. Sci. Rev.* 72, 159–168.
- Dürkop, A., Holbourn, A., Kuhnt, W., Zuraidda, R., Anderson, N., Grootes, P.M., 2008. Centennial scale climate variability in the Timor Sea during Marine Isotope Stage 3. *Mar. Micropaleontol.* 66, 208–221.
- Endicott, P., Ho, S.Y.W., Metspalu, M., Stringer, C., 2009. Evaluating the mitochondrial timescale of human evolution. *Trends Ecol. Evol.* 24, 515–521.
- Eriksson, A., Betti, L., Friend, A.D., Lycett, S.J., Singarayer, J.S., von Cramon-Taubadel, N., Valdes, P.J., Balloux, F., Manica, A., 2012. Late Pleistocene climate change and the global expansion of anatomically modern humans. *Proc. Natl. Acad. Sci. U. S. A.* 109, 16089–16094.
- Faith, J.T., O'Connell, J.F., 2011. Revisiting the late Pleistocene mammal extinction record at Tight Entrance Cave, southwestern Australia. *Quat. Res.* 76, 397–400.
- Fernandes, V., Alshamali, F., Alves, M., Costa, M.D., Pereira, J.B., Silva, N.M., Cherni, L., Harich, N., Cerny, V., Soares, P., Richards, M.B., Pereira, L., 2012. The Arabian Cradle: mitochondrial relicts of the first steps along the southern route out of Africa. *Am. J. Hum. Genet.* 90, 347–355.
- Field, J., Filios, M., Wroe, S., 2008. Chronological overlap between humans and megafauna in Sahul (Pleistocene Australia–New Guinea): a review of the evidence. *Earth Sci. Rev.* 89, 97–115.
- Fifield, L.K., Bird, M.I., Turney, C.S.M., Hausladen, P.A., Santos, G.M., di Tada, M.L., 2001. Radiocarbon dating of the human occupation of Australia prior to 40 ka BP – successes and pitfalls. *Radiocarbon* 43, 1139–1145.
- Fillios, M., Field, J., Charles, B., 2010. Investigating human and megafauna co-occurrence in Australian prehistory: mode and causality in fossil accumulations at Cuddie Springs. *Quat. Int.* 211, 123–143.
- Flood, J., 1983. *Archaeology of the Dreamtime*. Collins, Sydney.
- Foley, R.A., Lahr, M.M., 1997. Mode 3 technologies and the evolution of modern humans. *Cambr. Archaeol. J.* 7, 3–36.
- Friedlaender, J.S., Friedlaender, F.R., Hodgson, J.A., Stoltz, M., Koki, G., Horvat, G., Zhadanov, S., Schurr, T.G., Merriwether, D.A., 2007. Melanesian mtDNA complexity. *PLoS ONE* 2, e248.
- Fu, Q., Meyer, M., Gao, X., Stenzi, U., Burbano, H.A., Kelso, J., Pääbo, S., 2013a. DNA analysis of an early modern human from Tianyuan Cave, China. *Proc. Natl. Acad. Sci. U. S. A.* 110, 2223–2227.
- Fu, Q., Mittnik, A., Johnson, P.L.F., et al., 2013b. A revised time scale for human evolution based on ancient mitochondrial genomes. *Curr. Biol.* 23, 553–559.
- Fu, Q., Li, H., Moorjani, P., et al., 2014. Genome sequence of a 45,000-year-old modern human from western Siberia. *Nature* 54, 445–449.
- Gammage, B., 2011. *The Biggest Estate on Earth: How Aborigines Made Australia*. Allen & Unwin, Sydney.
- Ghirotto, S., Penso-Dolfin, L., Barbujani, G., 2011. Genomic evidence for an African expansion of anatomically modern humans by a southern route. *Hum. Biol.* 83, 477–489.
- Gillespie, R., Brook, B.W., Baynes, A., 2006. Short overlap of humans and megafauna in Pleistocene Australia. *Alcheringa Spec. Iss.* 1, 163–185.
- Green, R.E., Krause, J., Briggs, A.W., et al., 2010. A draft sequence of the Neandertal genome. *Science* 328, 710–722.
- Gronau, I., Hubisz, M.J., Gulko, B., Danko, C.G., Siepel, I., 2012. Bayesian inference of ancient human demography from individual genome sequences. *Nat. Genet.* 43, 1031–1034.
- Grün, R., Eggins, S., Aubert, M., Spooner, N.A., Pike, A.W.G., Müller, W., 2010. ESR and U-series analyses of faunal material from Cuddie Springs, NSW, Australia: implications for the timing and extinction of the Australian megafauna. *Quat. Sci. Rev.* 29, 596–610.
- Habeck-Fardy, A., Nanson, G.C., 2014. Environmental character and history of the Lake Eyre Basin, one seventh of the Australian continent. *Earth Sci. Rev.* 132, 39–66.
- Hallam, S.J., 1977. The relevance of Old World archaeology to the first entry of man into new worlds: colonization seen from the Antipodes. *Quat. Res.* 8, 124–148.
- Hautala, S.J., Sprintall, J., Potemra, J.T., Ilhude, A.G., Chong, J.C., Pandoe, W., Bray, N., 2001. Velocity structure and transport of the Indonesian Throughflow in the major straits restricting flow into the Indian Ocean. *J. Geophys. Res.* 106 (96), 19527–19546.
- Henn, B.M., Cavalli-Sforza, L.L., Feldman, M.W., 2012. The great human expansion. *Proc. Natl. Acad. Sci. U. S. A.* 109, 17758–17764.
- Hernandez, R.D., Kelley, J.L., Elyashiv, E., Melton, S.C., Auton, A., McVean, G., 1000 Genomes Project, Sella, G., Przeworski, M., 2011. Classic selective sweeps were rare in recent human evolution. *Science* 331, 920–924.
- Hershkovitz, I., Marder, O., Ayalon, A., et al., 2015. Levantine cranium from Manot Cave (Israel) foreshadows the first European modern humans. *Nature*. <http://dx.doi.org/10.1038/nature14134>.
- Hiscock, P., 1990. How old are the artefacts at Malakunanja II? *Archaeol. Ocean.* 25, 122–124.
- Hiscock, P., 2008. *Archaeology of Ancient Australia*. Routledge, London.
- Hiscock, P., 2013. Occupying new lands: global migrations and cultural diversification with particular reference to Australia. In: Graf, K.E., Ketron, C.V., Waters, M.R. (Eds.), *Paleoamerican Odyssey*, Department of Anthropology, Texas A&M University, College Station (TX), pp. 3–11.
- Hoffecker, J.F., 2009. The spread of modern humans in Europe. *Proc. Natl. Acad. Sci. U. S. A.* 106, 16040–16045.
- Hogg, A., Turney, C.S.M., Palmer, J., et al., 2013. The New Zealand Kauri (*Agathis australis*) research project: a radiocarbon dating intercomparison of Younger Dryas wood and implications for IntCal 13. *Radiocarbon* 55, 2035–2048.
- Hope, J.H., Hope, G.S., 1976. Palaeoenvironments for man in New Guinea. In: Kirk, R.L., Thorne, A.G. (Eds.), *The Origins of the Australians*. Australian Institute of Aboriginal Studies, Canberra, pp. 29–53.
- Horton, D.R., 1981. Water and woodland: the peopling of Australia. *Aust. Inst. Aborig. Stud. News.* 16, 21–27.
- Hudjashov, G., Kivisild, T., Underhill, P.A., Endicott, P., Sanchez, J.J., Lin, A.A., Shen, P., Oefner, P., Renfrew, C., Villems, R., Forster, P., 2007. Revealing the prehistoric settlement of Australia by Y chromosome and mtDNA analysis. *Proc. Natl. Acad. Sci. U. S. A.* 104, 8726–8730.
- Hughes, P., Spooner, N., Questriax, D., 2014. Landscape history in the Hunter Valley, NSW: why there is a multitude of Holocene archaeological sites but so few Pleistocene sites. *Aust. Archaeol.* 79, 34–44.
- Hunt, C.D., Gilbertson, D., Rushworth, G., 2012. A 50,000-year record of late Pleistocene tropical vegetation and human impact in lowland Borneo. *Quat. Sci. Rev.* 37, 61–80.
- Irwin, G., 1992. *The Prehistoric Exploration and Colonisation of the Pacific*. Cambridge University Press, Cambridge.
- Jones, R., 1989. East of Wallace's Line: issues and problems in the colonization of the Australian continent. In: Mellars, P., Stringer, C. (Eds.), *The Human Revolution: Behavioural and Biological Perspectives on the Origins of Modern Humans*. Princeton University Press, Princeton, pp. 743–782.
- Kaal, J., Schellekens, J., Nierop, K.J.G., Cotizas, A.M., Muller, J., 2014. Contribution of organic matter molecular proxies to interpretation of Lynch's Crater record (NE Australia). *Palaeogeogr. Palaeoclim. Palaeoecol.* 414, 20–31.
- Kershaw, A.P., 1986. Climatic change and aboriginal burning in north-east Australia during the last two glacial/interglacial cycles. *Nature* 322, 47–49.
- Kershaw, A.P., van der Kaars, S., Moss, P.T., 2003. Late Quaternary Milankovitch-scale climatic change and variability and its impact on monsoonal Australasia. *Mar. Geol.* 201, 81–95.
- Klein, R.G., 2009. *The Human Career: Human Biological and Cultural Origins*, third ed. University of Chicago Press, Chicago.
- Lambeck, K., Chappell, J., 2001. Sea level change through the last glacial cycle. *Science* 292, 679–686.
- Langley, M.C., Clarkson, C., Ulm, S., 2011. From small holes to grand narratives: the impact of taphonomy and sample size on the modernity debate in Australia and New Guinea. *J. Hum. Evol.* 61, 197–208.
- Law, W.B., Cropper, D.N., Petchey, F., 2010. Djadjjiling Rockshelter: 35,000 ¹⁴C years of Aboriginal occupation in the Pilbara, Western Australia. *Aust. Archaeol.* 70, 68–71.
- Leavesley, M.G., Chappell, J., 2004. Buang Merabak: additional early radiocarbon evidence of the colonisation of the Bismarck Archipelago, Papua New Guinea. *Antiquity* 78 (301). Project Gallery.
- Lima-Ribeiro, M.S., Diniz-Filho, J.A.F., 2014. Obstinate Overkill in Tasmania? The closest gaps do not probabilistically support human involvement in megafaunal extinctions. *Earth Sci. Rev.* 135, 59–64.
- Liu, W., Jin, C.Z., Zhang, Y.Q., et al., 2010. Human remains from Zhirendong, South China, and modern human emergence in East Asia. *Proc. Natl. Acad. Sci. U. S. A.* 107, 19201–19206.
- Lopes de Santos, R.A., DeDecker, P., Hopmans, E.C., Magee, J.W., Mets, A., Sinninghe Damsté, J.S., Schouten, S., 2013. Abrupt vegetation change after the Late Quaternary megafaunal extinction in southeastern Australia. *Nat. Geosci.* 6, 627–631.
- Lourandos, H., 1980. Change or stability? Hydraulics, hunter-gatherers and population in temperate Australia. *World Archaeol.* 11, 245–264.
- Lourandos, H., Ross, A., 1994. The great 'Intensification Debate': Its history and place in Australian archaeology. *Aust. Archaeol.* 39, 54–63.
- Lowry, D.C., Jennings, J.N., 1974. The Nullarbor karst. *Zeit. Geomorphol.* 18, 35–81.
- Lynch, A.H., Beringer, J., Kershaw, A.P., Marshall, A., Mooney, S., Tapper, N., Turney, C., van der Kaars, S., 2007. Using the paleorecord to evaluate climate and fire interactions in Australia. *Ann. Rev. Earth Planet. Sci.* 35, 215–239.
- Macaulay, V., Hill, C., Achilli, A., et al., 2005. Single, rapid coastal settlement of Asia revealed by analysis of complete mitochondrial genomes. *Science* 308, 1034–1036.
- Manne, T., Veth, P.M., 2015. Late Pleistocene and early Holocene exploitation of estuarine communities in northwestern Australia. *Quat. Int.* <http://dx.doi.org/10.1016/j.quaint.2014.12.049> (in press).
- McEvoy, B.P., Powell, J.E., Goddard, M.E., Visscher, P., 2011. Human population dispersal 'Out of Africa' estimated from linkage disequilibrium and allele frequencies of SNPs. *Genome Res.* 21, 821–829.
- Mellars, P., Gori, K.C., Carr, M., Soares, P.A., Richards, M.B., 2013a. Genetic and archaeological perspectives on the initial modern human colonization of southern Asia. *Proc. Natl. Acad. Sci. U. S. A.* 110, 10699–10704.
- Mellars, P., Gori, K.C., Carr, M., Soares, P.A., Richards, M.B., 2013b. Genetics. *Proc. Natl. Acad. Sci. U. S. A.* 110. Supplementary Information (on line).
- Mijares, A.S., Détroit, F., Piper, P., Grün, R., Bellwood, P., Aubert, M., Champion, G., Cuevas, N., De Leon, A., Dizon, E., 2010. New evidence for a 67000-year-old human presence at Callao Cave, Luzon, Philippines. *J. Hum. Evol.* 59, 123–132.
- Miller, G.H., Fogel, M.L., Magee, J.W., Gagan, M.K., Clarke, S., Johnson, B.J., 2005. Ecosystem collapse in Pleistocene Australia and a human role in megafaunal extinction. *Science* 309, 287–290.
- Miller, G.H., Magee, J.W., Fogel, M.L., Gagan, M.K., 2007. Detecting human impacts on the flora, fauna, and summer monsoon of Pleistocene Australia. *Clim. Past* 3, 463–473.

- Miller, G.H., Magee, J.W., Johnson, B.J., Fogel, M., Spooner, N.A., McCulloch, M.T., Ayliffe, L.K., 1999. Pleistocene extinction of *Genyornis newtoni*: human impact on Australian megafauna. *Science* 283, 205–208.
- Mooney, S.D., Harrison, S.P., Bartlein, P.J., et al., 2011. Late Quaternary fire regimes of Australasia. *Quat. Sci. Rev.* 30, 28–46.
- Morse, K., Cameron, R., Reynan, W., 2014. A tale of three caves: new dates for Pleistocene occupation in the inland Pilbara. *Aust. Archaeol.* 79, 167–178.
- Murphy, B.P., Bowman, D.M.J.S., 2012. What controls the distribution of tropical forest and savanna? *Ecol. Lett.* 15, 748–758.
- Murphy, B.P., Williamson, G.J., Bowman, D.M.J.S., 2012. Did central Australian megafaunal extinction coincide with abrupt ecosystem collapse or gradual climate change? *Glob. Ecol. Biogeogr.* 21, 142–151.
- Murray, A.S., Roberts, R.G., 1997. Determining the burial time of single grains of quartz using optically stimulated luminescence. *Earth Planet. Sci. Lett.* 15, 163–180.
- Notaro, M., Wyröll, K.H., Chen, G., 2011. Did aboriginal vegetation burning impact on the Australian summer monsoon? *Geophys. Res. Lett.* 1, L11704.
- O'Connell, J.F., Allen, J., 1998. When did humans first arrive in Greater Australia, and why is it important to know? *Evol. Anthropol.* 6, 132–146.
- O'Connell, J.F., Allen, J., 2004. Dating the colonization of Sahul (Pleistocene Australia–New Guinea): a review of recent research. *J. Archaeol. Sci.* 31, 835–853.
- O'Connell, J.F., Allen, J., 2012. The restaurant at the end of the universe: modelling the colonisation of Sahul. *Aust. Archaeol.* 74, 5–17.
- O'Connell, J.F., Allen, J., Hawkes, K., 2010. Pleistocene Sahul and the origins of seafaring. In: Anderson, A., Barrett, J., Boyle, K. (Eds.), *The Global Origins and Development of Seafaring*. McDonald Institute for Archaeological Research, Cambridge, pp. 57–68.
- O'Connor, S., 2007. New evidence from East Timor contributes to our understanding of earliest modern human colonisation east of the Sunda Shelf. *Antiquity* 81, 523–535.
- O'Connor, S., Barham, A., Spriggs, M., Veth, P., Aplin, K., St Pierre, E., 2010. Cave archaeology and sampling in the tropics: a case study from Lene Hara cave, a 42,000 year old occupation site in East Timor, Island Southeast Asia. *Aust. Archaeol.* 71, 29–40.
- O'Connor, S., Veth, P., 2000. The world's first mariners: savanna dwellers in an island continent. In: O'Connor, S., Veth, P. (Eds.), *East of Wallace's Line: Studies of Past and Present Maritime Cultures of the Indo-Pacific Region*. Balkema, Rotterdam, pp. 99–138.
- Olley, J.M., Roberts, R.G., Yoshida, H., Bowler, J.M., 2006. Single-grain optical dating of grave-infill associated with human burials at Lake Mungo, Australia. *Quat. Sci. Rev.* 25, 2469–2474.
- Oppenheimer, S., 2009. The great arc of dispersal of modern humans: Africa to Australia. *Quat. Int.* 202, 2–13.
- Oppenheimer, S., 2012. A single southern exit of modern humans from Africa: before or after Toba? *Quat. Int.* 258, 88–99.
- Oppenheimer, S., 2014. Modern humans spread from Aden to the Antipodes: with passengers and when? In: Dennell, R., Porr, M. (Eds.), *Southern Asia, Australia, and the Search for Human Origins*. Cambridge University Press, Cambridge, pp. 228–242.
- Parton, A., Farrant, A.R., Leng, M.J., Schwenninger, J.-L., Rose, J.L., Uerpmann, H.-P., Parker, A.G., 2013. An early MIS 3 pluvial phase in Southeast Arabia: climatic and archaeological implications. *Quat. Int.* 300, 62–74.
- Pavildes, C., Gosden, C., 1994. 35,000-year-old sites in the rainforests of West New Britain, Papua New Guinea. *Antiquity* 68, 604–610.
- Pearce, R.H., Barbetti, M., 1981. A 38,000-year-old archaeological site at Upper Swan, Western Australia. *Archaeol. Ocean.* 16, 173–178.
- Petraglia, M.D., Ditchfield, P., Jones, S., Korisettar, R., Pal, J.N., 2012. The Toba volcanic super-eruption, environmental change, and hominin occupation history in India over the last 140,000 years. *Quat. Int.* 258, 119–134.
- Petraglia, M.D., Haslem, M., Fuller, D.Q., Boivin, N., Clarkson, C., 2010. Out of Africa: new hypotheses and evidence for the dispersal of *Homo sapiens* along the Indian Ocean rim. *Ann. Hum. Biol.* 37, 288–311.
- Pope, K.D., Terrell, J.E., 2008. Environmental setting of human migrations in the circum-Pacific region. *J. Biogeogr.* 35, 1–21.
- Poznik, G.D., Henn, B.M., Yee, M.-C., Sliwerska, E., Euskirchen, G.M., Lin, A.A., Snyder, M., Quintana-Murci, L., Kidd, J.M., Underhill, P.A., Bustamante, C.D., 2013. Sequencing Y Chromosomes resolves discrepancy in time to common ancestor of males versus females. *Science* 341, 562–565.
- Price, G.J., Webb, G.E., Zhao, J.X., Feng, Y.-x., Murray, A.S., Cooke, B.N., Hocknull, S.A., Sobbe, I.H., 2011. Dating megafaunal extinction on the Pleistocene Darling Downs, eastern Australia: the promise and pitfalls of dating as a test of extinction hypotheses. *Quat. Sci. Rev.* 30, 899–914.
- Prideaux, G.J., Gully, G.A., Couzens, A.M.C., Ayliffe, L.K., Jankowski, N.R., Jacobs, Z., Roberts, R.G., Hellstrom, J.C., Gagan, M.K., Hatcher, L.M., 2010. Timing and dynamics of Late Pleistocene mammal extinctions in southwestern Australia. *Proc. Natl. Acad. Sci. U. S. A.* 107, 22157–22162.
- Przywolniak, K., 2005. Long-term transitions in hunter-gatherers of coastal north-western Australia. In: Veth, P., Smith, M., Hiscock, P. (Eds.), *Desert Peoples: Archaeological Perspectives*. Blackwell, Carlton (VIC), pp. 177–205.
- Rasmussen, M., Guo, X., Wang, Y., et al., 2011. An Aboriginal Australian genome reveals separate human dispersals into Asia. *Science* 334, 94–98.
- Reich, D., Patterson, N., Kircher, M., et al., 2011. Denisova admixture and the first modern human dispersals into Southeast Asia and Oceania. *Am. J. Hum. Genet.* 89, 516–528.
- Reimer, P., Bard, E., Bayliss, et al., 2013. IntCal13 and Marine13 radiocarbon age calibration curves, 0–50,000 years cal BP. *Radiocarbon* 55, 1869–1887.
- Reyes-Centano, H., Ghiroto, S., D etroit, F., Grimaud-Herv , D., Barbujani, G., Harvati, K., 2014. Genomic and cranial phenotype data support multiple modern human dispersals from Africa and a southern route into Asia. *Proc. Natl. Acad. Sci. U. S. A.* 111, 7248–7253.
- Richter, D., Tostevin, G., Skrdla, P., Davies, W., 2009. New radiometric ages for the Early Upper Palaeolithic type locality of Brno-Bohunice (Czech Republic): comparison of OSL, IRSL, TL and ¹⁴C dating results. *J. Archaeol. Sci.* 36, 708–720.
- Rito, T., Richards, M.B., Fernandes, V., Alshamali, F., Cerny, V., Pereira, L., Soares, P., 2013. The first modern human dispersals across Africa. *PLoS ONE* 8 (11), e80031.
- Roberts, R.G., Brook, B.W., 2010. Turning back the clock on the extinction of megafauna in Australia. *Quat. Sci. Rev.* 29, 593–595.
- Roberts, R.G., Flannery, T.F., Ayliffe, L.K., Yoshida, H., Olley, J.M., Prideaux, G.J., Laslett, G.M., Baynes, A., Smith, M.A., Jones, R., Smith, B.L., 2001. New ages for the last Australian megafauna: continent-wide extinction about 46,000 years ago. *Science* 292, 1888–1892.
- Roberts, R.G., Jones, R., Smith, M.A., 1990. Thermoluminescence dating of a 50,000 year old occupation site in northern Australia. *Nature* 345, 153–156.
- Roberts, R.G., Jones, R., Spooner, N.A., Head, M.J., Murray, A.S., Smith, M.A., 1994. The human colonization of Australia: optical dates of 53,000 and 60,000 bracket human arrival at Deaf Adder Gorge, Northern Territory. *Quat. Sci. Rev.* 13, 575–583.
- Roberts, R.G., Spooner, N.A., Jones, R., Cane, S., Olley, J.M., Murray, A.S., Head, M.J., 1996. Preliminary luminescence dates for archaeological sediments on the Nullarbor Plain, South Australia. *Aust. Archaeol.* 42, 7–16.
- Roscoe, P., 2005. Foraging, ethnographic analogy and Papuan pasts: contemporary models for the Sepik-Ramu past. In: Pauley, A., Attenborough, R., Golson, J., Hide, R. (Eds.), *Papuan Pasts: Cultural, Linguistic and Biological Histories of Papuan-speaking Peoples*. Pacific Linguistics, Research School of Pacific and Asian Studies, Australian National University, Canberra, pp. 555–584.
- Rose, J.L., 2010. New light on human prehistory in the Arabo-Persian Gulf Oasis. *Curr. Anthropol.* 51, 849–883.
- Rule, S., Brook, B.W., Haberle, S.G., Turney, C.S.M., Kershaw, A.P., Johnson, C.N., 2012. The aftermath of megafaunal extinction: ecosystem transformation in Pleistocene Australia. *Science* 335, 1483–1486.
- Sakaguchi, S., Bowman, D.M.J.S., Prior, L.D., Crisp, M.D., Linde, C.C., Tsumura, Y., Isagi, Y., 2013. Climate, not Aboriginal landscape burning, controlled the historical demography and distribution of fire-sensitive conifer populations across Australia. *Proc. Roy. Soc. B* 280, 20132182.
- Sankararaman, S., Patterson, N., Li, H., P ab o, S., Reich, D., 2012. The date of interbreeding between Neandertals and modern humans. *PLoS Genet.* 8 (10), e1002947.
- Scally, A., Durbin, R., 2012. Revising the human mutation rate: implications for understanding human evolution. *Nat. Genet.* 13, 745–753.
- Segural, L., Wyman, M.J., Przeworski, M., 2014. Determinants of mutation rate variation in the human germline. *Ann. Rev. Genom. Hum. Genet.* 15, 47–70.
- Shea, J.J., 2003. The Middle Paleolithic of the East Mediterranean Levant. *J. World Prehist.* 17, 313–394.
- Shen, G., Wang, W., Wang, Q., Shao, J., Collerson, K., Zhou, C., Tobias, P.V., 2002. U-series dating of Liujiang hominid site in Guanxi, southern China. *J. Hum. Evol.* 43, 817–829.
- Siddall, M., Rohling, E.J., Almqvist-Labin, A., Hemleben, Ch., Meischner, D., Schmelsler, I., Smeed, D.A., 2003. Sea level fluctuations during the last glacial cycle. *Nature* 423, 853–858.
- Sillitoe, P., 2002. Always been farmer-foragers? Hunting and gathering in the Papua New Guinea Highlands. *Anthropol. Forum* 12, 45–76.
- Slack, M.J., 2008. Between the Desert and the Gulf: Evolutionary Anthropology and Aboriginal Prehistory in the Riversleigh/Lawn Hill Region, Northern Australia (unpublished PhD thesis). Department of Anthropology, University of Sydney.
- Slack, M.J., Fullagar, R.L.K., Field, J.H., Border, A., 2004. New Pleistocene ages for backed artefact technology in Australia. *Archaeol. Ocean.* 39, 131–137.
- Smith, M.A., 2013. *The Archaeology of Australia's Deserts*. Cambridge University Press, Cambridge.
- Soares, P., Ermini, L., Thomson, N., Mormina, M., Rito, T., Rohl, A., Salas, A., Oppenheimer, S., Macaulay, V., Richards, M.B., 2009. Correcting for purifying selection: an improved human mitochondrial molecular clock. *Am. J. Hum. Genet.* 84, 1–20.
- Soares, P., Alshamali, F., Pereira, J.B., Fernandes, V., Silva, N.M., Afonso, C., Costa, M.D., Musilova, E., Macaulay, V., Richards, M.B., Cerny, V., Pereira, L., 2012. The expansion of mtDNA haplogroup L3 within and out of Africa. *Mol. Biol. Evol.* 29, 915–927.
- Stringer, C.B., Andrews, P., 1988. Genetic and fossil evidence for the origin of modern humans. *Science* 239, 1263–1268.
- Summerhayes, G., Leavesley, M., Fairbairn, A., Mandui, H., Field, J., Ford, A., Fullagar, R., 2010. Human adaptation and plant use in highland New Guinea 49,000 to 44,000 years ago. *Science* 330, 78–81.
- Torrence, R., Neall, V., Doelman, T., Rhodes, E., McKee, C., Davies, H., Bonetti, R., Guglielmetti, A., Manzoni, A., Oddone, M., Parr, J., Wallace, C., 2004. Pleistocene colonisation of the Bismarck Archipelago: new evidence from New Britain. *Archaeol. Ocean.* 39, 101–130.
- Trueman, C.N.G., Field, J.H., Dortch, J., Charles, B., Wroe, S., 2005. Prolonged coexistence of humans and megafauna in Pleistocene Australia. *Proc. Natl. Acad. Sci. U. S. A.* 102, 8381–8385.
- Turney, C.S.M., Bird, M.I., Fifield, L.K., Roberts, R.G., Smith, M., Dortch, C.E., Gr n, R., Lawson, E., Ayliffe, L.K., Miller, G.H., Dortch, J., Cresswell, R.G., 2001a. Early

- human occupation at Devil's Lair, southwestern Australia. 50,000 years ago. *Quat. Res.* 55, 3–13.
- Turney, C.S.M., Bird, M.I., Fifield, L.K., Kershaw, A.P., Cresswell, R.G., Santos, G.M., di Tada, M.L., Hausladen, P.A., Youping, Z., 2001b. Development of a robust ^{14}C chronology for Lynch's Crater (North Queensland, Australia) using different pretreatment strategies. *Radiocarbon* 43, 45–54.
- Turney, C.S.M., Flannery, T.F., Roberts, R.G., Reid, C., Fifield, L.K., Higham, T.F.G., Jacobs, Z., Kemp, N., Calhoun, E.M., Kalin, R.M., Ogle, N., 2008. Late-surviving megafauna in Tasmania, Australia, implicate human involvement in their extinction. *Proc. Natl. Acad. Sci. U. S. A.* 105, 12150–12153.
- Turney, C.S.M., Kershaw, A.P., Clemens, S.C., Branch, N., Moss, P.T., Fifield, L.K., 2004. Millennial and orbital variations of El Niño/Southern oscillation and high-latitude climate in the last glacial period. *Nature* 428, 306–310.
- Ulm, S., 2011. Coastal foragers on southern shores: Marine resource use in northeast Australia since the late Pleistocene. In: Bicho, N.F., Haws, J.A., Davis, L.G. (Eds.), *Trekking the Shore: Changing Coastlines and the Antiquity of Coastal Settlement, Interdisciplinary Contributions to Archaeology*. Springer Science+Business Media, New York, pp. 441–461.
- van Holst Pellekaan, S., 2013. Genetic evidence for the colonization of Australia. *Quat. Int.* 285, 44–56.
- Walshe, K., 2012. Port Augusta hearth site dated to 40,000 years. *Aust. Archaeol.* 74, 106–110.
- Ward, I., Larcombe, P., Veth, P., 2015. A new model for coastal resource productivity and sea-level change: the role of physical sedimentary processes in assessing the archaeological potential of submerged landscapes from the Northwest Australian Continental Shelf. *Geoarchaeol* 30, 19–31.
- Webb, R.E., Rindos, D.J., 1997. The mode and tempo of the initial human colonisation of empty landmasses: Sahul and the Americas compared. In: Barton, C.M., Clark, G.A. (Eds.), *Rediscovering Darwin: Evolutionary Theory and Archeological Explanation*, *Archeological Papers of the American Anthropological Association* No. 7, pp. 233–257.
- Webb, S.D., 2008. Megafauna demography and late Quaternary climatic change in Australia: a predisposition to extinction. *Boreas* 37, 329–345.
- Weninger, B., Jöris, O., 2008. A ^{14}C age calibration curve for the last 60 ka: the Greenland-Hulu U/Th timescale and its impact on understanding the Middle to Upper Paleolithic transition in Western Eurasia. *J. Hum. Evol.* 55, 772–778.
- Westaway, K.E., Morwood, M., Roberts, R.G., Rokus, A.D., Zhao, J.-x., Storm, P., Aziz, F., van den Burgh, G., Hadi, P., de Vos, J., 2007. Age and biostratigraphic significance of the Punung Rainforest Fauna, East Java, Indonesia, and implications for Pongo and Homo. *J. Hum. Evol.* 53, 709–717.
- White, J.P., O'Connell, J.F., 1982. *A Prehistory of Australia, New Guinea, and Sahul*. Academic Press, Sydney.
- Wild, S., 1985. Voyaging to Australia: 30,000 years ago. In: *Proceedings of Ausgraph 85, Third Australasian Conference on Computer Graphics*, Brisbane.
- Williams, A.N., 2013. A new population curve for prehistoric Australia. *Proc. Roy. Soc. B* 280, 20130486.
- Wollstein, A., Leo, O., Becker, C., Brauer, S., Trent, R.J., Numberg, P., Stoneking, M., Kayser, M., 2010. Demographic history of Oceania Inferred from genome-wide data. *Curr. Biol.* 20, 1983–1992.
- Wright, R.V.S., 1971. The Archaeology of the Gallus site, Koonalda Cave. *Prehistory Series 5*. In: *Australian Aboriginal Studies*, 26. Australian Institute of Aboriginal Studies, Canberra.
- Wroe, S., Field, J., 2006. Extinction of the Australian megafauna: a review of the evidence for human causation and an alternative paradigm. *Quat. Sci. Rev.* 25, 2692–2703.
- Wroe, S., Field, J.H., Archer, M., Grayson, D.K., Price, G.J., Louys, J., Faith, J.T., Webb, G.E., Davidson, I., Mooney, S.D., 2013. Climate change frames debate over the extinction of megafauna in Sahul (Pleistocene Australia-New Guinea). *Proc. Natl. Acad. Sci. U. S. A.* 110, 8777–8781.
- Zuo, W., Smith, F.A., Charnov, E.L., 2013. A life history approach to Late Pleistocene megafaunal extinction. *Am. Nat.* 182, 524–531.