Larcombe, P. & Ward, I.A.K.

Comment on Williams et al., 2018, 'Sea-level change and demography during the last glacial termination and early Holocene across the Australian continent'.

1. Introduction

Williams et al. (2018; hereafter referred to as W18) is one of a number of papers to emerge that use a large radiometric dataset (collated by Williams et al., 2014) to interpret Aboriginal demography and associated cultural change. W18 coupled the radiometric dataset with data on sea-level change to interpret past human demography across Australia. W18 explicitly noted some limitations of the data employed, but did not acknowledge or address the major limitations of the associated analysis (see also Robin et al., 2015). Underlying their analysis is the idea that if a large enough sample is used and is treated statistically, sources of error will be minimal (Torring, 2015). Unfortunately, critical unaddressed issues lie outside statistics (see also Crema et al., 2017) and relate to the patchy nature of the record arising from the complexities of coastal and marine sedimentary processes. Below, we describe some of these critical issues.

2. Sea-level data and calculation of changes in shoreline location

There are substantive issues regarding W18's analysis. Firstly, although acknowledging the reality of variable rates of sea-level change, W18 used averaged sea-level data. In the absence of detailed data, averaging appears a reasonable approach, but unfortunately, it has the consequence of masking the actual variations, which are vital in controlling the actual drivers on coastal environments. Fluctuations are evident in all high-resolution studies of past sea level, whether based on sea-level indicators (Larcombe et al., 1995; Lewis et al., 2013; Webster et al., 2018), isotopic or faunal proxies (Horton et al., 2007; Kemp et al., 2010), stratigraphic relationships (Larcombe & Carter, 1998) or direct observations.

Secondly, to calculate past shoreline positions, W18 used the method of Anderson and Bisset (2015, their section 6.3.1), which simply used modern bathymetry for the calculations. Therefore, their method did not cover the diversity of sedimentary regime and sediment bodies on Australia's post-glacial and modern continental shelves (Harris, 1995; Hill et al., 2009; Larcombe & Carter 2004, 2009; McNeil et al., 2016; Boyd et al., 2005), and of the different physical drivers to change (Larcombe et al., 2018). Sediments and the drivers of physical change are critical influences on coastal environments, potential human occupation, site formation, site preservation and site identification (Inda et al. 2017; Larcombe et al., 2018). Hence, it is incorrect to assume that the results are meaningful when spread across very different shelves, or different sections of them.

Thirdly, as explained by Larcombe et al. (2018), neither the present measured bathymetry nor the shoreline's past association with sea level are reliable indicators of past coastal

geomorphology. During transgression, in many coastal environments highly favourable for humans, such as estuaries and sheltered embayments behind rocky headlands, occupants are likely to have experienced pulses of changed coastal configuration associated with the coastal sediments interacting with the local bathymetry and changing physical drivers, rather than experiencing any constant unidirectional change. Therefore, and opposite to W18's conclusions regarding the "impacts" of MWP1a, such pulsed change is probably more likely to occur across relatively low gradient portions of the shelves, where available mobile sediment bodies have greater potential to influence shelf and shoreline character.

Finally, whilst W18's analysis was restricted to the period 35 - 8 ky BP, there are important messages in later events. Major sediment-associated changes in coastal morphology have occurred since 8 ky BP, such as on the central Great Barrier Reef shelf Australia (Carter et al., 1993; Lewis et al., 2014). Sea-level change is a factor controlling the location of key physical drivers (Larcombe et al., 2018), but there are many circumstances where it plays only a minor role in controlling sedimentary environments (see also Bowdler, 2010; Lewis et al., 2013; Morrison et al., 2018).

Taken together, these issues introduce significant doubt in W18's conclusions about where (and when) the "impacts" of sea-level change were greatest.

3. Coastal productivity

Coastal productivity around the Last Glacial Maximum and through the transgression is used by W18 to inform interpretations of past human demographics. The statement of low coastal productivity throughout the terminal Pleistocene - specifically of mangroves and shellbeds - is based on W18's text:

"... studies of contemporary mangals [that show] they typically occupied the edge of tolerance limits, and prolonged sea-level change of >12 cm/100 years would have resulted in collapse of these communities (Ellison and Stoddart, 1991; Kathiresan and Bingham, 2001; Duke et al., 2017) - values that were substantially exceeded on an annual basis between 15 and 8 ka."

These references simply do not support W18's text:

- Ellison & Stoddart's (1991, E&S91) work relates only to sediment-starved environments (those "in the absence of significant allochthonous sediment input"). In such cases, the system's capacity to respond to sea-level rise relies on the accumulation of organic matter. E&S91 extrapolated their results to sediment-rich mangrove environments, but without justification and in the apparent absence of understanding their dynamics. The hydrodynamic and sediment dynamic features of mangrove systems is widely documented (Wolanski et al. 2001; Larcombe & Ridd, 1996; Bryce et al., 2003), as is their application to system evolution during transgression (e.g. Wolanski & Chappell, 1996; Woodroffe, 2018). Further, neither E&S91 or W18 distinguished between open coast and estuarine mangrove systems, the second type of which are typically far larger in extent, more productive and inherently physically resilient.

- Kathiresan & Bingham (2001: 63; K&B01) quote E&S91 regarding rates of sea-level rise that might stress mangrove systems, but in their very next sentence, K&B01 explicitly note two contradictory papers that consider that twice such rates might be tolerated. W18 did not refer to this fact. Later in their chapter, K&B01, (p. 76) wrote, "responses will vary among locations and will depend on the local rate of the rise and the availability of sediment to support reestablishment of the mangroves" and provide ample references in support. Again, W18 did not mention this.
- Duke et al., 2018 present no data or arguments relating mangroves to sea-level rise and it is unclear why they were referenced in this context.

Regarding shellbeds, W18 stated that:

"Such a rapidly changing shoreline would similarly have affected the establishment and growth of shell beds, which while no doubt present were also likely struggling with the fluctuating conditions."

It is not clear what type of shellbeds they refer to, their depositional environment(s) and nature. There is no explanation of what the fluctuating environmental conditions were, nor why this would be detrimental to shellbed initiation and development.

Therefore, regarding mangrove systems and shellbeds during transgression, W18's arguments about coastal productivity and the implications for coastal human populations are wholly unsupported.

4. Past human demographics

W18 conclude that

"hunter-gatherer populations remained low throughout the terminal Pleistocene, but...[with] an increasing utilization of inland and riverine environments at ~35-30 ka as coastline recession disrupted marine resources",

and

"[a] rapid population increase immediately following MWP1a, in tandem with large numbers of archaeological sites being established around the southeast and northwest parts of the continent, [reflecting] migration of hunter-gatherers inland from the recently submerged crustal shelf."

Regarding the use of large radiocarbon datasets ('big data') to interpret past human demographics, W18 stated that criticisms (e.g. Attenbrow and Hiscock, 2015; Torfing, 2015) are often groundless, but did not justify this assertion. Critical aspects of these criticisms remain neglected by W18. Whilst W18 did consider time-dependent taphonomic loss, they did not deal with environment-dependent taphonomic loss (the spatially uneven

taphonomic and depositional processes of Crema et al., 2017). There is a lack of appreciation of site-formation processes, and particularly here, of coastal and marine sedimentary processes as key influences on the archaeological record (see also Robins et al. 2015).

Further, many arguments in W18 border appear circular because interpreted parameters, such as past populations and amount of land utilized, that themselves derive from the original radiocarbon dataset, are used as primary evidence for a human response to coastal change.

W18 assert that coastal recession disrupted coastal resources, but do not argue why. As noted above, because of the resilience that mobile sediments provide, there is no *prime facie* reason why coastal change necessarily results in 'disrupted' coastal resources. For example, on the NWS, the large tidal ranges, strong tidal currents and cyclones experienced through the Post-Glacial transgression (e.g. Ward et al., 2013; see also Larcombe et al., 2018) are conditions in which coasts would adjust very rapidly to change, and may develop large areas of potentially productive intertidal and subtidal substrates.

Further, the derived data plotted as W18's Fig. 1. D, E & F are also based solely on radiocarbon data rather than using the more informative technique of considering all available types of dating information (cf. Bubenzer et al., 2007; Hughes et al., 2017). Any apparent correlation in time (at 35 – 30 ka and after MWP1a at ~ 13.5 ka) between asserted population density and human migration is weak, and thus affects interpretations of human point-to-point strategies and use of cryptic refuges. Correlation does not demonstrate cause and effect, and even more so where the factors in question depend on so many other parameters which are themselves very difficult or impossible to correct for (see also Contreras, 2016).

In passing, we note that Fig. 1 B indicated a constant rates of loss of land of 9 M km² through the LGM, which is inconsistent with the text "*During the LGM, sea-level was relatively stable, and changes to the shoreline minor perhaps only 0.5–3 m per year, equating to ~12–71 m per generation*". Should the caption have been "Area of land remaining"?

The above issues combine such that W18's presentation of known human demographic change and its drivers are unjustified.

5. Conclusion

The understanding of archaeological site formation and taphonomy (*sensu* Lyman, 2010) continues to progress in terrestrial (Ward & Larcombe, 2003; Dubois et al., 2017), coastal (Inda et al., 2017) and marine (Ward et al., 2000; Winton 2015; Quinn & Smith, 2017) contexts. Recently, Larcombe et al. (2018) demonstrated that physical processes are critical controls of coastal sedimentary environments and archaeological sites, so that interpretation of such sites must include the influence of such processes on environment, potential occupation, site formation, site preservation and site identification. W18 did not consider physical processes. Further, radiometric data used by W18 were divorced from

their vital sedimentary contexts, and the nature of the data's combination with bathymetric and sea-level datasets contain significant flaws. Many interpretations were arrived at without explicit consideration of alternatives. Taken together, it is hard to conclude that W18's conclusions stand up to scrutiny, and they could only be viewed as archaeological hypotheses that require appropriate testing.

6. Acknowledgements

PL thanks RPS MetOcean for funding some time on this paper. IW is a PDRA funded by Australian Research Council grant DP170100812 "The Deep History of Sea Country: Climate, Sea Level and Culture", which part-funded time on this paper. PL & IW acknowledge Pippin Larcombe for editorial assistance.

7. References

1. Attenbrow, V., Hiscock, P., 2015. Dates and demography: are radiometric dates a robust proxy for long-term prehistoric demographic change? *Archaeol. Ocean.*, 50, 30 - 36.
2. Bastida, R., Grosso, M., Elkin, D., 2008. The Role of Benthic Communities and Environmental Agents in the Formation of Underwater Archaeological Sites. Ch. 10. In: Leshikar-Denton, M.E., Luna Erreguerena, P. *Underwater and maritime archaeology in Latin America and the Caribbean*. California: Left Coast Press.
3. Bowdler, S. (2010) The empty coast: *Conditions for human occupation in southeast Australia during the late Pleistocene*. In: S. Haberle, J. Stevenson & M. Prebble (Eds.) *Altered ecologies: fire, climate and human influence on terrestrial landscapes* (Terra Australia 32): 177-85. Canberra: ANU E Press. Available at: <http://epress.anu.edu.au>.
4. Boyd, R., Ruming, K., & Roberts, J. J. 2004. Geomorphology and surficial sediments of the southeast Australian continental margin. *Australian Journal of Earth Sciences*, 51, 743-764.
5. Bubenzer, O., Besler, H., Hilgers, A., 2007. Filling the gap: OSL data expanding 14C chronologies of Late Quaternary environmental change in the Libyan Desert. *Quaternary International*, 175, 41-52.
6. Carter, R. M., Johnson, D. P., & Hooper, K. G. 1993. Episodic post-glacial sea-level rise and the sedimentary evolution of a tropical continental embayment (Cleveland Bay, Great Barrier Reef shelf, Australia). *Australian Journal of Earth Sciences*, 40, 229-255.
7. Contreras, D.A., 2016. Correlation is not enough: building better arguments in the archaeology of human environmental interactions. pp. 3 - 22. In: Contreras, D.A. (ed.) *The Archaeology of Human-Environment Interactions*. Routledge: New York.
8. Crema, E.R., Bevan, A., Shennan, S., 2017. Spatio-temporal approaches to archaeological radiocarbon dates. *J. Archaeological Science* 87, 1 - 9.
9. Dubois, C. M. F., de Rubin, J. C. R., 2017. Environmental dynamics and formation processes of the archaeological record in Latin America. *Geoarchaeology*, doi:org.ezproxy.library.uwa.edu.au/10.1002/gea.21657
10. Harris, P. T., 1995. Marine geology and sedimentology of the Australian continental shelf. In: L. P. Zann & P. Kailola (eds.) *The State of the Marine Environment Report for Australia*, Technical Annex 1, 11-24. Department of the Environment, Sport and Territories, Canberra.
11. Hill P. J., De Deckker, P., von der Borch, C. & Murray-Wallace, C. V. (2009) Ancestral Murray River on the Lacepede Shelf, southern Australia: Late Quaternary migrations of a

- major river outlet and strandline development. *Australian Journal of Earth Sciences*, 56, 135-157. doi.org/10.1080/08120090802546993
12. Horton, B., Culver, S., Hardbattle, M.I.J., Larcombe, P., Milne, G., Morigi, C., Whittaker, J.E., Woodrofe, S.A. 2007. Reconstructing Holocene sea-level change for the central Great Barrier Reef (Australia) using subtidal foraminifera. *Journal of Foraminiferal Research*, 37(4) 327-343. doi:10.2113/gsjfr.37.4.327
 13. Hughes, P.J., Sullivan, M.E., Hiscock, P., 2017. Palaeoclimate and human occupation in southeastern arid Australia. *Quaternary Science Reviews*, 163, 72 - 83.
 14. Inda, H., Del Puerto, L., Capdepon, I., Bracco, R., 2017. Formation processes of coastal archaeological sites: A changing prehistoric scenario on the Atlantic shore of Uruguay, *Geoarchaeology*, 32(6), 633-645.
 15. Kathiresan, K. & Bingham, B.L. 2001. Biology of Mangroves and Mangrove Ecosystems. *Advances in Marine Biology* 40, 81-251.
 16. Kemp, A. C., Vane, C. H., Horton, B. P., Culver, S. J. 2010. Stable carbon isotopes as potential sea-level indicators in salt marshes, North Carolina, USA. *The Holocene*, 20(4), 623-636.
 17. Larcombe, P. & Ridd, P.V. 1996. *Dry season hydrodynamics and sediment transport in mangrove creeks*. In: Pattiaratchi, C. (Ed.) *Mixing processes in estuaries and coastal seas*. Coastal & Estuarine Studies, Vol. 46, American Geophysical Union, pp.388-404.
 18. Larcombe, P. and Carter, R.M. 2004. Cyclone pumping, sediment partitioning and the development of the Great Barrier Reef shelf system: a review. *Quaternary Science Reviews*, 23, 107-135.
 19. Larcombe, P., Carter, R.M., Dye, J., Gagan, M.K., Johnson, D.P., 1995. New evidence for episodic post-glacial sea-level rise, central Great Barrier Reef, Australia. *Marine Geology*, 127(1), 1-44.
 20. Larcombe, P. & Carter, R.M., 1998. Sequence architecture during the Holocene transgression: an example from the Great Barrier Reef shelf, Australia. *Sedimentary Geology*, 117, 97-121.
 21. Larcombe, P., Ward, I. A. K., & Whitley, T. 2018. Physical sedimentary controls on subtropical coastal and shelf sedimentary systems: Initial application in conceptual models and computer visualizations to support archaeology. *Geoarchaeology*, <https://doi.org/10.1002/gea.21681>.
 22. Lewis, S.E., Sloss, C.R., Murray-Wallace, C.V., Woodroffe, C.D., Smithers, S.G., 2013. Post-glacial sea-level changes around the Australian margin: a review. *Quat. Sci. Rev.* 74, 115 - 138. <https://doi.org/10.1016/j.quascirev.2012.09.006>.
 23. Lewis, S. E., Olley, J., Furuichi, T., Sharma, A., & Burton, J., 2014. Complex sediment deposition history on a wide continental shelf: Implications for the calculation of accumulation rates on the Great Barrier Reef. *Earth and Planetary Science Letters*, 393, 146-158.
 24. Lyman, R.L. 2010. What taphonomy is, what it isn't, and why taphonomists should care about the difference. *Journal of Taphonomy* 8 (1), 1-16.
 25. McNeil, M. A., Webster, J. M., Beaman, R. J., & Graham, T. L., 2016. New constraints on the spatial distribution and morphology of the *Halimeda* bioherms of the Great Barrier Reef, Australia. *Coral Reefs*, 35, 1343-1355.
 26. Morrison, A.E., Cochrane, E.E., Rieth, T., Horrocks, M., 2018. Archaeological and sedimentological data indicate Lapita settlement on a newly formed coastal plain: Tavua Island, Mamanuca Group, Fiji. *The Holocene*, 28(1), 44-55.

27. Quinn, R., Smyth, T. A. G., 2017. Processes and patterns of flow, erosion, and deposition at shipwreck sites: a computational fluid dynamic simulation. *Archaeological and Anthropological Sciences*. <https://doi.org/10.1007/s12520-017-0468-7>
28. Robins, R., Hall, J., Stock, E., 2015. Geoarchaeology and the archaeological record in the coastal Moreton Region, Queensland, Australia. *Quaternary International* 385, 191 – 205.
29. Romagnoli, F., Nishiaki, Y. Rivals, F., Vaquero, M., 2018. Time uncertainty, site formation processes, and human behaviours: New insights on old issues in high-resolution archaeology. *Quaternary International*, 474, 99-102.
30. Torfing, T., 2015. Neolithic population and summed probability distribution of 14C dates. *J. Archaeological Science*, 63, 193 – 198.
31. Ward, I., Larcombe, P., 2003. A process-orientated approach to archaeological site formation: application to semi-arid northern Australia. *Journal of Archaeological Science*, 30, 1223-1236.
32. Ward, I., Larcombe, P., Veth, P., 2000. A New Process-Based Model for Wreck Site Formation. *Journal of Archaeological Science*, 26(5), 561-567.
33. Ward, I., Larcombe, P., Mulvaney, K., 2013. A geoarchaeological assessment of the submerged archaeological landscapes of the Dampier Archipelago, Western Australia. *Quaternary International*, 308-309, 216 – 229.
34. Webster, J.M., Braga, J.C., Humblet, M., et al. Loughheed, B.C., 2018. Response of the Great Barrier Reef to sea-level and environmental changes over the past 30,000 years. *Nature Geoscience*, 11, 426–432.
35. Williams, A.N., Ulm, S., Cook, A.R., Langley, M.C., Collard, M., 2013. Human refugia in Australia during the last glacial maximum and terminal Pleistocene: a geospatial analysis of the 25-12ka Australian archaeological record. *J. Archaeol. Sci.* 40, 4612e4625. <https://doi.org/10.1016/j.jas.2013.06.015>.
36. Williams, A.N., Ulm, S., Smith, M., Reid, J., 2014. AustArch: A Database of 14C and Non-14C Ages from Archaeological Sites in Australia - Composition, compilation and review. *Internet Archaeol.* 2014, 36. <https://doi.org/10.11141/ia.36.6>.
37. Williams, A.N., Ulm, S., Sapienza, T., Lewis, S., Turney, C.S.M., 2018. Sea-level change and demography during the last glacial termination and early Holocene across the Australian continent. *Quaternary Science Reviews* 182, 144-154.
38. Winton, T., 2015. Understanding the interactive nature of 'in-situ' processes for management of submerged cultural heritage material. *J. Australasian Institute for Maritime Archaeology*, 39, 71 – 83.
39. Wolanski, E., & Chappell, J., 1996. The response of tropical Australian estuaries to a sea level rise. *Journal of Marine Systems*, 7(2-4), 267-279.
40. Wolanski, E., Mazda, Y., Furukawa, K., Ridd, P., Johnson, K., Spagnol, S., and Stieglitz, T., 2001. *Water circulation in mangroves, and its implications for biodiversity*. In: Wolanski, Eric, (ed.) *Oceanographic Processes of Coral Reefs*. CRC Press Inc, Washington, DC, USA, pp. 53-76.
41. Woodroffe, C. D., 2018. Mangrove response to sea level rise: palaeoecological insights from macrotidal systems in northern Australia. *Marine and Freshwater Research*, 69(6), 917-932.