There can be no confidence that the “first marine” and “*in situ*” artefact scatters in the Dampier Archipelago, NW Australia are in their primary archaeological context.

Ingrid Ward^{1*} , Piers Larcombe¹ , Peter J. Ross², Chris Fandry³.

Short title –

Assessing whether coastal archaeological artefact scatters are *in situ*, NW Australia

1. Archaeology, School of Social Sciences, University of Western Australia

2. Flinders University, South Australia

3. RPS MetOcean, Perth, Western Australia.

* Corresponding author

Email: Ingrid.Ward@uwa.edu.au

[†]Ingrid Ward and Piers Larcombe are joint senior authors

Revised version sent to PLOS ONE on 29/09/2021, recommended by the Handling Editor for acceptance.

This amended version dated 9th Nov 2021 contains an expanded Table 1 and updated acknowledgements.

Note that the in-text referencing may be imperfect in places because of the various versions combined in Word to make this pre-print. (Please get in touch for any required clarification).

Abstract

The absence of known prehistoric underwater cultural heritage (UCH) sites on the inner continental shelf of Australia stands in stark contrast to the thousands of sites revealed elsewhere in the world. Two recent claims – Dortch et al. (D2019) and Benjamin et al. (B2020) – put forward the first *in situ* (i.e., primary context) marine UCH sites in the shallow waters of the Dampier Archipelago, NW Australia, each arguing the stone artefact scatters are at least 7000 years old and are now submerged because of post-glacial sea-level rise. From the data published in D2019 and B2020, we assess the explicit and implicit assumptions and uncertainties of these claims. We include new results of hydrodynamic modelling, new data on coastal erosion and new bathymetric data of northern Flying Foam Passage, leading to a reinterpretation of the archaeology and the sites' sedimentary settings.

Whilst the presented lithic material of D2019 and B2020 clearly includes cultural artefacts, we find that the arguments for the sites being of primary context and reflecting early Holocene land surfaces do not stand up to scrutiny and that the available evidence is insufficient to establish the facts. In describing the assumptions and uncertainties in D2019 and B2020, we include example tests to help resolve them. On balance, it appears that these sites are intertidal, and many or all artefacts are likely to have been reworked. These and similar sites would benefit from a thorough appraisal of past and present coastal processes to produce a defensible understanding of site formation processes before it is possible to determine their true nature and significance, noting that, even as secondary sites, they would still inform our understanding of process and change. Such work would support more powerful contributions to submerged prehistory than attempts to seek the first, the earliest, the oldest or deepest.

Keywords: Australia, archaeology, underwater cultural heritage, secondary context, submerged prehistoric cultural landscape

1. Introduction

As Lemke [1] outlines, this is an exciting time for submerged prehistoric archaeology with significant growth in awareness, research and associated publications and an ever-increasing number of underwater finds, particularly in the Northern Hemisphere. This fluorescence and what it might contribute to origins of human culture, global human expansion, early coastal adaptations and the origins of seafaring is now beginning in more southern parts of the globe [2, 3]. In northern Australia there is a particular incentive to explore drowned landscapes and their coastlines because they were probably primary points of entry for initial colonization and population dispersal, currently estimated to have occurred at around 50,000 cal BP or earlier [4, 5]. Around one-third of the Australian continent was drowned by rising sea levels after the last glacial maximum (c. 21,000 cal BP) for which there is no record of human occupation. Taken together, the incentives for researchers to begin to reveal the missing elements are very high.

Several studies have outlined the potential for preservation and discovery of submerged prehistoric cultural sites in Australia [6, 7, 8, 9, 10, 11, 12], and these helped achieve the first dedicated Commonwealth-funded project, called 'Deep History of Sea Country' (DHSC) [13]. The DHSC project includes focus on the World Heritage site of the Dampier Archipelago (*Murujuga*) (Fig 1), where the dense terrestrial archaeological record includes petroglyphs or engravings that, in part, document how the people, *Ngurra-ra Ngarli*, adapted to the changing environments associated with post-glacial sea-level rise [14, 15, 16]. The documentation of these engravings was part of another Commonwealth-funded project in the same area, 'Murujuga: Dynamics of the Dreaming'. Two publications emanating from these projects are the prime focus of this paper.

Fig 1 Map of the Dampier Archipelago showing locations of areas mentioned in the text (Contains modified Copernicus Sentinel data (2020) processed by Sentinel Hub)

In late 2019, Dortch et al. [17] - hereafter D2019 - presented a “preliminary characterisation” of lithic materials located in the intertidal zone of Dolphin Island (Fig 1) as part of the *Dynamics of the Dreaming* project, stating that they represented the first documented Australian marine archaeological evidence for Aboriginal occupation *prior* to Holocene sea-level inundation, and that the site was in primary context. In mid-2020, Benjamin et al. [18] - hereafter B2020 - put forward their own claim for the first Australian underwater archaeological sites, located at Cape Bruguieres (CB) and Flying Foam Passage (FF) (Fig 1, Fig 2), stating that the work demonstrated “*the existence of in situ archaeological material on pre-inundation land surfaces associated with periods of lower sea level*”, and documented “*Australia’s first confirmed ancient underwater archaeological sites from the continental shelf*”. B2020 asserted that they paid “*particular attention*” to “*the taphonomic and depositional histories of the underwater artefacts and their geomorphic context in order to examine*

83 *systematically a range of alternative hypotheses that might account for their present position”.*

84 B2020’s interpretation has since been presented as fact by the same team [19 p3, 20, 21, 22, 23, 31,
85 32, 33]. In a region where tidal ranges are around 5 m, the precise meaning of ‘submerged’ or
86 ‘underwater’ can be subjective, and in our view the term ‘continental shelf’ was used loosely.
87 Nonetheless, it is critical to understand whether the sites and the collected data have been
88 subjected to sufficient testing to justify such claims. We also comment on the use of the term “*in*
89 *situ*”.

90 Being such major claims, much interest was generated by these papers and there was a great deal of
91 associated publicity. For example, for B2020, this included ~80 separate news articles [e.g., 24, 25,
92 26, 27, 28, 29] in addition to numerous Twitter feeds and blog posts [30] and several citations [e.g.,
93 31, 32, 33] (not including five self-citations). All of these accepted B2020’s claims. Our paper
94 presents a thorough review of the sedimentary settings of D2019’s and B2020’s sites, and we include
95 new results of hydrodynamic modelling, new data on coastal erosion and new bathymetric data of
96 northern FF Passage. The evidence and arguments lead to a significant reinterpretation of the
97 archaeology. In scrutinising these papers, we raise a series of important broader issues for marine
98 geoarchaeology and the level of importance given to underwater finds, simply for being underwater
99 [1].

100 Among various assertions, both D2019 and B2020 claim that the “underwater” lithic scatters are i) in
101 primary context and ii) distinct from emergent stone artefact scatters on the immediately adjacent
102 shorelines. B2020 further claim that their main site in the CB channel is older than 7000 cal BP. In
103 this paper we reassess these and other claims in the context of physical processes and logical
104 arguments, concluding that at present, the justifications for these claims are unfortunately weak.
105 We believe that the work reflects poorly designed and method-driven research, on which we
106 present some alternative hypotheses and ways of testing site formation. Whilst the sites appear
107 unlikely to represent *in situ* primary contexts, we argue that their value as likely secondary contexts

is important and could contribute to much-needed theoretical aspects of underwater site formation [1, 34].

Fig 2 LIDAR-derived digital terrain model (vegetation removed) showing the distribution of underwater and intertidal stone artefacts recorded in CB channel using nautical chart tide data (Data: [18, 35] Marked tidal elevation lines are relative to Cape Legendre (see also Table 1, Fig 5).

1.1. The Dampier Archipelago (Murujuga)

Our reinterpretation of these sites as likely secondary deposits, rather than primary as reported by B2020 and D2019, partly rests on understanding several key oceanographic processes not adequately accounted for by these authors. The Dampier Archipelago (*Murujuga*) is comprised of 42 islands and islets located at latitude 20°20'S – 20°45'S and longitude 116°24'E – 117°05'E (Fig 1). Most of the Archipelago's islands are surrounded by inner-shelf waters <10 m deep, the largest of which include Enderby Is., Dolphin Is. and Legendre Is. (Fig 1), the latter of which is a remnant of a

Late Pleistocene dune-barrier system and shoreline [35 p157]. At the Last Glacial Maximum (LGM) ~21,000 cal BP, these features lay on a broad, flat coastal plain stretching nearly 160 km across [36, 37]. The modern seabed within the 20 and 30 m isobaths represents the approximate location of the Late Pleistocene shoreline around ~8,000 cal BP prior to islandisation [35 p70]. The Holocene relative highstand in sea level is prominent in NW Australia, forming a period of around 7000 years with sea levels ~1.5-3 m higher than today [38, 101].

Cyclones can drive strong wind-generated currents [43], driving regional flows mostly towards the SW, in the same direction as regional cyclone-driven along-shelf sediment transport [39, 40, 41, 42]. Non-cyclonic winds are strongly seasonal, and in general, the westerly component of summer winds drives shelf waters gently towards the east, past the islands located west of Burrup Peninsula and northwards through Mermaid Sound, whilst winter winds generate the reverse [43].

Tides are semi-diurnal and macro-tidal (range of ~5 m) and their intra-decadal variations are mainly affected by the lunar perigee subharmonic, causing a dominant 4.4-year cycle in elevations along the Northwest Shelf [44]. Longer-period changes are un-investigated to date. Tidal currents are stronger at the outer areas of the Archipelago and strongest in some passages. Measurements in the 1980s indicated that the highest tidal current speeds (~2 m/s) in FF Passage occur during ebb (falling) tides that flow SSW, driven by a combination of topographic funnelling and a significant difference in water levels (up to 0.5 m) between Nickol Bay and the Dampier Archipelago [45, see also 43 p32].

Our modelling results (Fig 3, Fig 4) agree very closely with the flow measurements and the key driving force of a gradient in surface water levels. There are no known measured data of current speeds at the CB channel site.

Fig 3 *a. Modelled sea levels within and around Flying Foam Passage (m relative to MSL) at the approximate time of peak ebb tidal currents at 07:00 h on 22 March 2011. There is up to 0.5 m difference between the centre of Mermaid Sound to the west of the islands and the centre of Nickol Bay to the east. b. Time series of sea level (m relative to AHD) in the centre of Flying Foam Passage (blue dot) and east of the islands (red dot) for the 22nd March 2011. Red arrows indicate timing of data presented in a and c. c. As 'a' for the subsequent peak flood currents, at 12:00 hours.*

Fig 4 Modelled tidal current speeds (at an elevation of 3.5 m below MSL) in the centre of Flying Foam Passage (red dot). a. Peak ebb tide, at 06:00 h on 22 March 2011. b. Peak flood tide, at 12:00 h on 22 March 2011. c. Time-series of modelled speeds at the centre of Flying Foam Passage for the period Jan-Jun 2011. Red arrows indicate timing of flood tide data presented in b. The peak tidal speed of the southward flowing ebb tide is 1.8 m/s, slightly stronger than the northward flood tide, of 1.5 m/s.

This region is one of Australia's most cyclone-prone, with an average of five cyclones per year occurring on the adjacent shelf, at least two of which make landfall [46], and the Dampier Archipelago itself is directly impacted by cyclone activity approximately every two years. Cyclone-associated surge in water levels may achieve several metres at the coast, for example a surge of +3.1 m occurred at Dampier with TC Orson [47], and an absolute water elevation of ~+6.6 m AHD was interpreted as having been achieved during TC Vance, 270 km to the SW [48]. Models based on hindcast data and synthetic cyclones indicate 100-yr return water levels of above 5 m AHD for most of the NWS shelf coastline [49]. Geological indicators of past higher water levels include three late Holocene storm beaches in the Dampier Archipelago area, ranging in elevation from ~+7.5 to +12 m AHD [50], and twelve individual wrack-line sites ranging in elevation from +5 to +8 m AHD and dated to the past 2500 years, with an estimated recurrence interval of 140 – 250 years [51].

Historic tsunamis are also well documented in WA [52, 53] and in the late Holocene [54] and given the key regional generation mechanisms (seismic activity, submarine slope failure) would have also taken place throughout the Post-Glacial transition and the Holocene [55, 56]. At regional and local levels, their past sedimentary effects are beginning to be documented [57, 58, 59], and knowledge is increasing of proxies to improve the identification and dating of depositional features left by tsunami inundation [e.g., 60, 61, 62, 63]. Across low coastal terrain, incident tsunamis are likely to consist of fast unidirectional flows with duration of several minutes to several tens of minutes [64, 65], and of enhanced speed in confined channels between islands or adjacent coastal embayments – like CB and FF Passage. Hence, tsunamis have clear capacity to mobilise sediments and cause coastal sedimentary change in this region.

The material above indicates that there are clearly many relevant oceanographic processes to be accounted for in any assessment of the mobility of archaeological artefacts in coastal environments in the Dampier Archipelago region over the last 10,000 years or so, and more broadly over the Post-Glacial transgression [8, 9, 42].

185

186 **2. Evaluating claims of primary submerged archaeological sites in the Dampier**
187 **Archipelago**

188 Both D2019 and B2020 argue that the artefacts found “underwater” were discarded in their
189 approximate *in situ* locations before sea-level rose to its modern elevation, and both papers
190 presented several 'alternative hypotheses' on the way to their conclusions. Both papers contain
191 many implicit and explicit assertions and assumptions, which we summarise as tables grouped into
192 broad issues of oceanography, geology, sediment transport and artefact analysis and which we
193 assess in detail below. We analyse whether and how each assertion and assumption was tested, and
194 we include in the summary tables some of our own alternative tests and/or explanations. We
195 indicate logical flaws, and we then arrive at a series of conclusions regarding the resulting
196 confidence to be had in the interpretations and conclusions drawn by D2019 and B2020.

197 **2.1. Water Levels and Tidal Currents**

198 Cyclone-associated oceanographic effects are discussed in the section ‘Sediment Transport’ below.
199 Here we focus on present and past water levels, and tidal currents. Using a drone, B2020 observed
200 significant differences in water level elevations at CB compared with the tidal predictions on the
201 nautical chart, from which they developed a revised tidal range scheme (Fig 5, Table 1). Their
202 scheme includes an absolute decrease in tide range of 1.0 m, formed by an increased elevation of
203 the highest tides of 0.25 m and more significantly, by an increased elevation of the lowest tides of
204 1.25 m.

Fig 5 Tidal ranges from the nautical chart [5] for Cape Legendre (left) compared to the tidal range scheme proposed by B2020 (right); HAT = Highest Astronomical Tide; AHD = Australian Height Datum; MSL = Mean Sea Level; LAT = Lowest Astronomical Tide.

Table 1 Comparison of Cape Legendre tide levels [35] with the B2020 tide range scheme and the Port of Dampier. B2020 tide range data provided by C. Wiseman (pers. comm. 2020). Note the asserted difference in LAT.

	Elevation (m AHD)						
	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT
Cape Legendre tide levels	2.05	1.55	0.25	-0.25	-0.75	-1.95	-2.65
B2020 tide range scheme tide levels	2.30	1.90	0.90	0.00	-0.30	-1.10	-1.40
Port of Dampier (King Bay)	2.48	1.77	0.47	0.00	-0.46	-1.77	-2.65

Sources:

Australian National Tide Tables: Australia, Papua & New Guinea. (The Hydrographer, Royal Australian Navy) 2015.

Port of Dampier Handbook, Pilbara Ports Authority, 2019. Available from: <https://www.pilbaraports.com.au/about-ppa/publications/forms-and-publications/forms-publications/handbook/2020/june/port-of-dampier-handbook>

Using their scheme, B2020 [p11] concluded that most (71%) of the “offshore” stone artefacts were “permanently submerged”, text which in normal use would indicate a location below the Lowest Astronomical Tide (LAT). If the nautical chart tide data are used, none of the artefacts would be permanently submerged. Whilst B2020 did not describe the hydrodynamic effects that might explain their revised tidal range scheme, rather than a radical change to the oceanography and tide datums,

an obvious alternative explanation in such a setting is ponding of the tide at low water (Table 2).

Three lines of evidence indicate this:

- Most importantly, the Mean Spring Range varies from 3.5 m at the western end of Cape Legendre to 3.7 m at the Port of Dampier [Port of Dampier Handbook, Pilbara Ports Authority, 2019. Available from: <https://www.pilbaraports.com.au/about-ppa/publications/forms-and-publications/forms-publications/handbook/2020/june/port-of-dampier-handbook>] (locations on Fig 1). First, this is a very small difference, of 0.2 m across 35 km, either side of Cape Bruguieres. In particular, the elevation of Mean Low Water Spring tide is about the same at both Cape Legendre and Dampier, at around -1.9 m AHD. It is physically impossible that between these sites at Cape Bruguieres the genuine open ocean low water level could be 1.25 m higher. Further, it is not possible in this environment for tides to generate the extremely steep surface gradient of 1:6400 required to produce a surface elevation difference of over 1.25 m at low water between Cape Bruguieres channel and the tidal recording station at the western end of Legendre Island, less than 8 km away.
- We compared an aerial photograph taken at 17:19 WA time on 29-05-2018 at predicted low tides of -1.66 m AHD, with a drone image B2020 acquired at 06:30 WA time on 02-10-2019 at a predicted low tide of -2.52 m AHD. Water levels from the aerial photograph appeared to be the same, at around -1.4 m AHD, coincident with B2020's asserted LAT.
- The site's bathymetry includes two enclosed seabed depressions that contain many of the artefacts (Fig 2, Fig 6).

In passing, we note that one large (20 – 25 cm) isolated artefact lies in deeper water (at -2.5 m AHD) in the western part of CB channel, ~ 175 m west of its nearest neighbour (Fig 2) – this artefact was not presented by B2020 [their Fig 5]. As well as the general high elevation of the site compared to regional low tides and the apparent intertidal and ponded setting, it is hard to see that the CB site

can realistically be described as “on the continental shelf” [B2020 p1] even with the inclusion of the deepest and most westerly artefact.

Fig 6 Elevation of Cape Bruguieres channel lithic artefacts (n=269) with distance along the channel (reduced to a single line of latitude). (Data: DHSC). Dashed line at -1.4 m AHD indicates B2020’s asserted LAT. Most artefacts are clustered in two depressions, one each side of what B2020 termed a “mid-channel sill”. Note that no data were presented by B2020 about the “455 artefacts and associated stone structures” of the “onshore assemblage” nor were made available in the supplementary data. (Adapted from 66).

Much of B2020s information was collected by divers, and we sought to investigate the likely flows on those days and thus put observations into context - it would be unusual for example for a technical scientific dive to be undertaken at a time of maximum tidal current. The dive logs were thus requested from the authors of B2020, to confirm the dates and times of the dives and to view the divers’ notes. No dive logs were supplied, neither were the dates and times of the dives, so whether the observed tides might represent maximum tidal flow speeds remains untested and indeed, until dive logs are made available, untestable. More importantly, there is an implicit assumption in B2020 that only tidal currents could be significant in the potential transport of artefacts through the last 7000 years, and that other currents, waves and other processes are not relevant. This assumption is incorrect and is addressed later in the section on Sediment Transport.

267

268 **Table 2.** Summary of logic used by B2020 relating to water levels and tidal currents, with alternative
 269 interpretations and suggested methods of testing their assumptions and assertions.

<i>Water Levels and Tidal Currents (B2020 only)</i>					
Used by B2020	This paper's view		Derived from B2020	This paper's view	
Explicit assumptions and assertions	Whether and how tested	Did the test provide a clear result?	Uncertainties (U) and Implicit Assumptions (IA)	Alternatives	Example methods that provide a test
Tidal range reduced by "local hydrodynamic effects" [p11]	Unclear	No explanation was provided.	U - No published data were provided to allow examination of their calculations. Some data were provided upon request (Table 1).	Site is intertidal and ponded at low water	Tidal datums and physical oceanography. Comparison of aerial photos from different predicted low tides. <i>In situ</i> empirical measurement of tidal dynamics using instruments.
Tidal range has remained constant throughout the Holocene	Untested	-	U - Misuses published modelling on tidal range changes over Post-Glacial transgression	Local tidal regime has varied through time, including through coastal geomorphic change	Sediment coring (biostratigraphy)

270

271 There is a further implicit assumption in B2020 that the tidal regime has remained constant
 272 throughout the Holocene. Local and regional tides cannot be assumed to have remained constant
 273 over time [8, 67] especially on a shelf of a shape and width where tidal amplification is a factor [68].
 274 Indeed, retrodictive tidal simulations indicate that both tidal range and tidal current speeds changed
 275 significantly through the transgression, with tidal currents at the (then) coast strongest during mid-
 276 transgression as the coast approached the outer edge of the Dampier Archipelago [8]. Simulations to
 277 date have used the modern bathymetry to represent the transgressive bathymetry, and so cannot

consider complexities introduced by the presence of mobile coastal sediment bodies, rocky promontories, complex bathymetry and inner-shelf islands, factors which are critical to understanding past and present flows in CB channel and FF Passage. In particular, such factors become especially important for the period of the Holocene highstand, because of the extended period over which a relatively stable suite of processes have acted upon shelf and coastal sediments. Understandably therefore, Ward et al. [8] did not present retrodictions within the Dampier Archipelago, and presented none for the mid-Holocene highstand period (see [8]; their Fig 4-6 inclusive). Indeed, they specifically stated that *“rather than trying to generate actual hindcasts of the tides (which, in our opinion, is not possible at present), we use the model to constrain the general nature of the past tides”* [8 p220] and, *“The results of this preliminary assessment highlight the need to improve definition of sea-level oscillations and past sedimentary regimes, particularly over the Holocene period”* [8 p227]. Thus, regarding FF Passage, B2020s use of Ward et al. [8] to assert *“the direction and relatively weak velocity of current flows once this depression was inundated by sea-level rise”* [B2020 p22] is unjustified, casting further uncertainty on B2020’s justification for the artefacts remaining in position over the last 7000 years.

Further, the extended Holocene highstand in relative sea level has great potential to i) increase sediment transport because in a shallow water environment and where there may have been sediment bodies to the W and NE that partially protected the environment from waves, an extra 2 m of water [38] affords increased opportunities for waves and currents to make their way to the site, and influence mobilisation of bed sediments, regionally and especially through otherwise shallow tidal channels such as at Cape Bruguieres, and ii) increase sediment generation as fringing reef flats were switched on to add locally produced carbonates to existing coastal sediments. These factors lead to the likely increased presence and movement of coastal Holocene sediment bodies. B2020 assess neither factor.

2.2. Geological Interpretation (including dating)

2.2.1. “Calcarenite” Terrace

Regarding the CB artefact scatter and FF Passage find spot, B2020 state that “*Geomorphological data and radiometric dates establish the chronological limits of the sites and demonstrate that they cannot be later than 7000 cal BP and 8500 cal BP respectively, based on the dates when they were finally submerged by sea-level rise*” [B2020 p1], where “*later than*” means younger than (M. O’Leary, pers. comm. 2020). Several of B2020s arguments are based around a so-called calcarenite beach terrace on the southern shore of the CB channel, now located high in the intertidal zone. This terrace is interpreted as “*cemented beachrock*” [B2020 p9] that was once an “*ebb tidal sand spit*” [B2020 p20]. Confusion around terminology is exacerbated by the lack of sedimentary description (Table 3) of the three key units - calcarenite beach terrace, aeolianite and beachrock. These are interpretative names and infer a different formation history, but no sedimentary details are given in B2020 to explain or justify them.

Table 3. Summary of logic used by B2020 relating to geological factors, with alternative interpretations and suggested methods of testing their assumptions and assertions.

<i>Geological Factors (B2020 only)</i>					
Used by B2020	This paper’s view		Derived from B2020	This paper’s view	
Explicit assumptions and assertions	Whether and how tested	Did the test provide a clear result?	Uncertainties (U) and Implicit Assumptions (IA)	Alternatives	Example methods that provide a test
The calcarenite terrace is “ <i>cemented beachrock</i> ” [p9] and/or an “ <i>ebb tidal sand spit</i> ” [p20]	Untested	-	U – lack of description and context weakens archaeological interpretation		Explore, describe and date any buried extension of ‘terrace’ (and differentiate from aeolianite)
The calcarenite terrace is mid-late Holocene in age	Direct dating (c. 1960 cal BP)	No	U – Was dated shell in life position?	Various	As above

Geological Factors (B2020 only)					
Used by B2020	This paper's view		Derived from B2020	This paper's view	
Explicit assumptions and assertions	Whether and how tested	Did the test provide a clear result?	Uncertainties (U) and Implicit Assumptions (IA)	Alternatives	Example methods that provide a test
Age of "offshore" artefacts is older than timing of marine inundation	Untested	-	IA – artefacts cannot be derived from onshore.	Offshore artefacts <7000 cal BP	Better constrain age from context and age of concretions
Age of onshore artefacts is same as calcarenite terrace	Untested	-		Various	Better constrain age from the surrounding sediments
Coastal morphology has remained constant over the last few millennia	Untested	-	U - Ignores likely coastal change during highstand	Coastal morphology has changed significantly in some parts of the Dampier Archipelago	Use of aerial imagery, sub-bottom geophysical survey, stratigraphy (onshore/offshore) and dating
Channel floor was inundated by the sea at 7000 yr BP, and <i>remained</i> exposed	Untested	-	IA - Holocene beach ridge north of N. Gidley Is. pre-dates formation of CB channel and extended across it	Channel opened when mouth breached by tides around 7000 cal BP.	As above, plus map seaward extension of channel, and date beach ridge north of Gidley Is.
Channel floor is an antecedent depression	Untested	-	-	Channel-base is buried	As above. Date channel floor sediments by OSL* dating on cores.
Colour indicates age; reddish deposits are MIS 5 or earlier and creamy-white deposits are Holocene [p4]	Untested	-	-	-	Describe and date coastal sediments, using OSL combined with ¹⁴ C dating

* Optically Stimulated Luminescence.

It is possible that this calcarenite terrace represents beachrock formed beneath coastal sediments in the intertidal zone [69], and later exhumed by coastal erosion. Such erosion in the past could also

have affected adjacent sedimentary deposits containing artefacts, meaning the artefacts would become transferred into a secondary context. A “*marine shell [unidentified] cemented into the upper surface*” of the beachrock [B2020 p10] was dated as 2141 - 1791 cal BP (Wk-49709). In an independent study of the Dolphin Island site, an *Anadara* sp. bivalve shell embedded in beachrock was similarly dated at 1809-1850 cal BP (Wk-49708) [70 p35], which is consistent with most occurrences of intertidal beachrock [71, 72]. No information is provided in either case regarding whether the shell was in life position, which if not, then the age estimate indicates only that the timing of cementation at the top of the sampled beachrock is younger than the absolute age. Whilst acknowledging that more work needed to be done, D2019 argued against a deflationary origin for the artefacts at the Dolphin Island site, based on an assumption of long-term coastal stability, assumed because crescentic beachrock formations are aligned parallel to the current beach [D2019 p10]. This argument ignores the fact that the exposure of beachrock is itself indicative of beach erosion and coastal regression [71]. Hence, and in contrast to D2019 and B2020, it cannot be ruled out that the intertidal artefacts at both sites have been derived from older sedimentary deposits and thus could be of secondary context. Nor can it be ruled out that the artefacts are younger than the dated beachrock and that erosion might have occurred in the last few centuries or decades. Further evidence and arguments are provided in the section below on Sediment Transport.

2.2.2. Channel Floor

In the CB channel, the “*relict Pleistocene aeolianite*” that forms the channel floor is argued to represent an “*antecedent depression that remained exposed for many millennia and later inundated by sea-level rise during the mid-Holocene (c. 7000 years ago)*” [B2020 p11]. Key evidence presented by B2020 to justify this interpretation of long exposure is the radiocarbon chronology of marine “*calcarenite*” immediately overlying the aeolianite [B2020 p11]. Their text states that “*Radiocarbon-dated marine shells (SUERC 90025, 90026, 90031, Table 1) were collected from a marine calcarenite that deposited on top of the aeolianite (sic) on the channel floor. These shells incorporated within*

the calcarenite are dated in the range 44,700 to 26,600 cal BP." As a minor note, this text that states "cal BP" is erroneous, because these numbers (44,700 to 26,600) appear in B2020's Table 1 [B2020 p11], in the column headed "Conventional 14C Age (years BP)" and the SUERC laboratory has confirmed that the tabulated data and the headings are correct (Philip Naysmith pers. comm. 2021). B2020's should thus read "dated in the range 47,500 to 30,500 cal BP" or "dated in the range 44,700 to 26,700 years BP".

Dates of this general age are close to the radiocarbon limit and may represent minimum ages, so the precise age of the calcarenite remain unknown. Further, regardless of the precise age, the age itself has little direct bearing on the underlying geomorphology, and certainly cannot be used to indicate constant exposure prior to accumulation of the calcarenite itself. Hence the relative age that B2020 assigned to the "offshore" artefact assemblage – stated as a minimum calibrated age of 7000 cal BP – appears unjustified. The age appears based on untested assumptions involving the elevation of the contemporary channel seabed against a composite regional sea-level curve [B2020 p25] and also requires that the offshore artefacts are in primary context.

2.2.3. Beach Ridge Complex

B2020 [p18 and p20] argue that the "Holocene beach ridge complex" along the west coast of North Gidley Island pre-dates the formation of the modern channel because there is no evidence of:

- i. remnants of ridges on the north side of the channel;
- ii. truncation of the ridge on the southern side of the channel; and finally,
- iii. that the presence of a sand spit on the southern side of the western end of the channel and the lack of modern mobile sediment in the channel together indicate the "current speeds are far too strong to allow the accumulation of beach-ridge sediments to fill the channel, as proposed in step one of the lag hypothesis" [B2020 p20].

Beginning with the first two points, the beach-ridge complex has not been dated and given that mean sea level has been within 2 m of modern levels for ~7000 years, there is a very wide range of

possible dates within it. That said, it appears entirely unnecessary to assert an age for the beach ridge complex because marine inundation of the site is not necessarily dependent on the presence or absence of the complex. In such a dynamic coastal environment, the record of accumulation, erosion, changed beach orientation, truncations and other processes and features are likely to be incomplete, and it is important to remember that the absence of evidence is not evidence of absence. Further, as is the present case, a beach-ridge complex can exist with an opening at its north, and with the CB channel open to the sea to the east. Finally, their hypothesised transport of sand *through* the site today cannot exclude *accumulation* at any time, and certainly not over a 7000-year period. Therefore, all three of the arguments for the dismissal of B2020's "lag hypothesis" do not stand up to scrutiny, the "lag hypothesis" itself appears unnecessary, and within it, the stated requirement [B2020 p18] that "*this beach ridge deposit originally extended continuously along the western shorelines of North Gidley and Cape Bruguieres Islands, blocking the channel that separates them today*" itself is not important.

Undefined "geomorphic evidence" is then used to explain the formation of the active tidal channel and *subsequent* accretion of the beach ridge complex against a newly formed spit along the southern end of the channel [B2020 p20]. As noted previously, no dates exist for the ridges, and they could post-date the formation of the channel. All coastal geomorphic reconstructions to date [8, 73, 74] show the channel opening sometime after 4000 cal BP, however, these models are all based on current bathymetry and cannot be assumed to be accurate. We consider that the timing of the present 0.6 x 0.3 km accumulation of sand to the NE of the sites, and any predecessors, will have been particularly important in affecting waves and currents at the sites.

394

395   **2.3. Sediment Transport**

396   **2.3.1. Regional indicators of long-term bedload transport direction**

397   Across the bulk of the inner and middle shelf in this region, coarse sands and larger grains are
398   generally only mobilised episodically, including by powerful regional along-shelf flows [40, 40, 43,
399   see also 75], especially flowing along the NW Shelf towards the SW, and with shear stress at the bed
400   enhanced further by waves, mainly in shelf waters shallower than 30 m. Further, on the open shelf,
401   wherever a strong asymmetry is shown in large bedforms, or wherever there is a succession of
402   adjacent bedform types, the pattern is consistent with flows and net bed sediment transport
403   directions driven by cyclone forcing [see also 76]. Where bathymetric constraints occur, such as in
404   the Dampier Archipelago, there is greater complexity to the potential forcing mechanisms and the
405   bedforms. Nonetheless, almost all the channels through the Burrup Peninsula region that have their
406   western end relatively sheltered from the seasonal reworking effect of southerly and westerly waves
407   have prominent sediment splays indicative of net bed sediment transport to the west (including
408   beside Keast Is., Cape Bruguieres Is., North Gidley Is. and Angel Is.; Fig 1, see also [21] their Figs. 5 &
409   6). No such splays occur at their eastern ends, and further the eastern sides of the Burrup Peninsula
410   and Dolphin Island exhibit only erosive shorelines with no constructive sedimentary features except
411   locally behind minor promontories.

412   In the northern part of FF Passage, east of Gidley Is., there is some recently available multi-beam
413   echosounder survey (MBES) data [79]. The data reveal the presence of a fixed-headland banner bank
414   (terminology of 77) extending for >1 km to the SW from the northern tip of Dolphin Island (Fig 7) and
415   upon the head of which there are active full-bedded small (wavelength 3 m) 2-D subaqueous dunes
416   [terminology of 78]. The presence of the bank indicates net transport of sand into FF passage from
417   Nickol Bay at this point. Further within FF Passage, west of Tozer Is., the MBES data also show long
418   trains (>250 m) of starved medium (spacing 8 m) 2D subaqueous dunes (78) with flow-perpendicular

crestlines and indeterminate asymmetry, on the bed at an elevation of ~ -10 m AHD (Fig 7). Given the flow speeds in the area (Fig 10), these are likely to be formed of very coarse sand or gravel and may vary in asymmetry with the tides.

Regardless of the precise combination of periodic and episodic generating mechanisms, all the available evidence indicates the likelihood of substantial net transport of available sand between Nickol Bay and Mermaid Sound, especially during cyclones, including through CB channel and FF Passage. Were coarser particles available, such as artefacts, they too might be transported, depending upon local hydrodynamic conditions.

Fig 7 Bathymetry of northern Flying Foam Passage [79]. Inset A – Trains of starved medium dunes. Inset B – Banner bank with small 2D dunes at the tip. Dune crest orientations indicated by blue lines. Vertical Datum is LAT at King Bay, Dampier, which is -2.649 m Australian Height Datum 1982.

434

435   **2.3.2. Cyclones as a driver of sediment mobilisation**

436   Both D2019 and B2020 argue minimal influence of tropical cyclones on the distribution of artefacts
437   into or within the marine environment. B2020 attempted to assess the impacts of cyclones using
438   aerial drone photography by comparing changes to the spatial distribution of artefacts in the
439   onshore assemblage before and after TC Veronica in March 2019, arguing that minimal impact from
440   this single event is representative of impact over multiple millennia (Table 4). Their argument is
441   unsustainable. Based on the available historical data, the region is directly impacted by one cyclone
442   every two years on average [46], so that, at such frequencies, an assemblage of ~ 2000 cal BP
443   (onshore) and ~ 7000 cal BP (offshore) would have experienced ~1000 and ~3500 cyclones
444   respectively. Visual impact from a single cyclone cannot possibly represent direct or indirect cyclonic
445   impacts on this or any other area over multiple millennia, especially as impacts will vary according to
446   the speed and direction of flows, frequency and size of waves and magnitudes of achieved water
447   levels [80] as well as various sedimentary and geological parameters.

448

449 **Table 4.** Summary of logic used by D2019 and B2020 regarding sediment transport, with alternative
 450 interpretations and suggested methods of testing their assumptions and assertions.

<i>Sediment transport</i>					
Used by D2019 and/or B2020	This paper's view		Derived from D2019 and/or B2020	This paper's view	
Explicit assumptions and assertions	Whether and how tested	Did the test provide a clear result?	Uncertainties (U) and Implicit Assumptions (IA)	Alternatives	Example methods that provide a test
(B2020) Tidal currents are weak and unable to transport artefacts over any significant distance	Untested, except for "diver observations" and a comparison with 'possible artefact material' on Goodwyn Is [18 p16].	No	U - Energy of site indicated by distribution of (historic) artefacts	Tidal and/or cyclone-driven currents can transport cobble-sized material	<i>In situ</i> empirical measurement of flow dynamics using instruments
(B2020) Observations from TC <i>Veronica</i> (Category 1) are meaningful	Before/after comparison of drone images of onshore artefacts	No	IA - One or two cyclones are representative of ~3,500 cyclones over a 7,000 yr period	Local effects of cyclones are cyclone-specific	Long-term monitoring; simulation studies
(D2019) No significant mobility of artefacts over the last 7000 yrs.	Untested	-	-	Cyclonic waves and flows along FF Passage mobilise intertidal material	As above; also define distribution of seabed sediments and bedforms.
(D2019) Expect a continuum between onshore and offshore artefacts if related	Observation (absence of evidence) & geochemical comparison of onshore and intertidal artefacts	No	IA - Artefact reworking is unidirectional (i.e., downslope)	Artefacts are impacted by landward and seaward processes, the majority of which are episodic in nature.	Long-term monitoring of artefact distribution; better constrain the age and dynamics of sedimentary context.

451

2.3.3. Recent shoreline changes assessed using Geoscience Australia's "Digital Earth Australia Coastlines"

Geoscience Australia's "Digital Earth Australia Coastlines" facility [81] uses satellite data and tidal models to define past shoreline changes, by identifying and using the location of MSL. For the southern margin of the western end of the CB channel, the data indicate an annual erosion rate of ~0.1 m/yr channel since 1988, and similar for the northern side, during which period more than 16 cyclones have passed within 50 km of Dampier Archipelago [46]. Whilst it might be tempting to extrapolate this measured rate over the last 33 years to longer periods to indicate many tens of metres of erosion, it would be unjustified, because there is no evidence for it. It is far more important that the coastline data forms clear evidence for decadal-scale coastal change, including in this case an episode of up to 12 m of coastal retreat in the late 1990's, and subsequent advance in the 2000s (Fig 8). Such changes indicate the likelihood of potential displacement of sediments and associated artefacts from the channel banks, as part of repeated episodes of burial and exposure, especially over the relevant period of many millennia.

Decadal-scale coastal change is also evident for FF Passage. Since 1988, the location of MSL along most of FF Passage has moved landward by 0.1 - 0.3 m/yr [65] although for a few years there is uncertainty in the precision of each individual MSL position and their associated beach profile. Also since 1988, the location of MSL in the southern part of the D2019 site has migrated seawards and landwards across a total distance of ~30 m [81] where the shore-normal spread of intertidal artefacts is <23 m. In the centre and north of the site, MSL has moved in location by a total of at least 50 m, where the documented intertidal artefacts are spread across up to ~100 m (Fig 9). We also note that between May 2018 and May 2019, Morrison [70 p31] observed the blocking of a drainage channel in the northern part of the beach site, and that there was "*a notable difference in stone visibility in parts of the intertidal zone*". It is unknown when, how rapidly and by what process

these sedimentary changes occurred, but these field observations further indicate the dynamic nature of the intertidal zone.

Fig 8 a - Satellite image of Cape Bruguieres Is. (upper left) and N. Gidley Is. with CB channel between them. b - Annual coastal position (advance = +ve; erosion = -ve; measured in metres) at six coastal locations (coloured dots in a) on N. Gidley Is., on the southern margin of western CB channel. Data represent the period 1988 – 2019, using 2019 as the origin [81]. Note the episode of erosion in the late 1990s.

2.3.4. Dolphin Island site of D2019

For the Dolphin Island intertidal zone, there is considerable variation in the location of sampled artefacts [D2019]. The elevation of most intertidal artefacts (65%) is within 0.5 m of the modern Mean Sea Level (MSL) while the remaining 35% lie in shallower water (Fig 10) and with only three artefacts between MHWS and the HAT.

Fig 9 Satellite image of Dolphin Is. beach showing variation in position of MSL since 1988 (data from [81]) and location of artefacts described by D2019. (Data: [17], [18]. (MSL location data are poor for 1991 and 1992 – this does not affect the analysis or conclusions).

No artefacts (lithic or historic) were found in water deeper than mean low water neap tide (Fig 10), but this was acknowledged as a possible consequence of sampling bias [D2019 p6]. D2019 reasoned that the intertidal artefacts were *in situ* because i) artefacts were not abraded or had rounded edges, and ii) “we would expect any movement of artifacts to reflect the longshore direction of marine currents” [D2019 p11]. D2019 also claim that currents in FF Passage would not transport objects, but it is unclear what type of currents they are referring to. D2019 assert that “Flying Foam Passage is well-protected from ocean surge and swell, even during extreme cyclonic events, and

relatively unaffected by seismic events which may induce tsunamis” [D2019 p9]. Regarding ocean swell waves, they are correct, but other mechanisms are available to generate waves and currents in the passage that might mobilise coastal sediments. These are described below.

Fig 10 Digital terrain model (vegetation removed) of the Dolphin Island beach and intertidal artefacts and their proximity to contemporary tidal ranges and storm surge extents (Data: [17], [18], SRTM data courtesy of US Geological Survey).

First, as noted above, FF Passage has fast spring tidal currents of up to 2 m/s [43, 45] (Fig 3, Fig 4). Regarding sediment transport, it is important to note that tidal currents are fast across all months and at the bed (Fig 11). Further, the intertidal site itself is also open to NNE winds with a fetch of over 8 km, and of 20 km with SW winds, so waves are relevant. For example, in the waters off the Dolphin Island site, persistent winds of 30 knots, a fetch of 10 km and water depth of 10 m would generate waves of significant wave height >0.9 m and period 3.4 s ([82], their equations Eqns. 3-28a, 3-39 and 3-40) which when refracted onto the intertidal zone would have ample energy to move sand. Indeed, almost the entire intertidal zone of D2019s site is unvegetated except for a few small

519 stands of mangroves at the back of the active beach. By far the largest stand is in the southern
520 central bay at 100 m x 20 m and most others are well under half that length and half that width (Fig
521 9). The relative lack of vegetation indicates persistent sediment mobility, unlike some other small
522 embayments in the passage that have more extensive stands of mangroves.

523 Overall, the coastline of FF Passage is rocky, heavily indented in places, and with a series of pocket
524 beaches generally best developed to the south of headlands, although locally variable in orientation.
525 The dominant pattern of longshore sand transport - meaning transport at the coast itself, which is
526 not necessarily related to that in the channel base - is probably southwards, evidenced by some
527 elongate well-formed beaches with accumulations of sand at their southern end, although there is
528 evidence of local reversals off headlands. Such reversals in longshore sand transport are not
529 unexpected given the strongly seasonal wind patterns in the region, where in winter, a subtropical
530 ridge moves north bringing dry easterly and south-easterly winds, and in summer winds tend to be
531 moderate northwesterlies, with episodic cyclones [83]. Further, in the transitional periods between
532 seasons, winds can be very variable each day and can vary greatly in direction between Legendre
533 Island and the town of Dampier [84].

534 Further, D2019 rule out runoff as a mechanism that might disturb and move artefacts from an
535 Aboriginal stone quarry on the beach ~ 50 m southeast of the main concentration of intertidal
536 artefacts. The argument includes using soil creep rates for a humid environment as provided from a
537 geomorphology textbook [85 p66]. Notwithstanding whether soil creep *per se* was actually meant,
538 D2019 appear to have been selective in their quote from the book, avoiding the adjacent text that
539 indicates “*much higher rates are found on slopes where there is no vegetation cover or high water*
540 *content*”. The arid Dampier Archipelago has little soil or vegetation cover and experiences episodic
541 very high rates of rainfall [see also 86], so would be likely to have higher rates of potential artefact
542 movement. Finally, edge damage of artefacts through transport over distances of 50 m was
543 “expected” by both D2019 [p9] (and by B2020 [p16]) but neither assertion was justified.

545

546 **Fig 11** Modelled peak ebb tide flow speeds (at 1 m above bed) through FF Passage: a. On the
547 ebb tide of 22 March 2011, at 07:00 h. b. Time-series of modelled speeds at the centre of
548 Flying Foam Passage (red dot) for the period Jan-Jun 2011. Red arrows indicate timing of
549 data presented in a.

550 Given the above issue of soil movement, that the documented magnitudes of coastal migration
551 represent only 32 years out of a proposed 7000 years for the site, and that the artefact data are
552 biased in their locations because of visibility issues (acknowledged by D2019), without further
553 evidence, it appears untenable to consider the Dolphin Island artefacts as *in situ*.

554

2.3.5. Flying Foam Passage site of B2020.

B2020 identified a single artefact found in a depression on the base of FF Passage. They state [p22] that the artefact's position and condition, combined with *"the direction and relatively weak velocity of current flows once this depression was inundated by sea-level rise"*, means that it *"is highly unlikely that this artefact arrived at its present position as a result of being eroded out from a terrestrial site on the nearest shoreline and transported by water action over such a distance"*. B2020 refer to Ward et al [8] regarding the flow speeds. There are two critical problems here:

i) as noted above, tidal currents alone through FF Passage are routinely well above 1 m/s, and are sufficiently fast at the bed (Fig 11) to begin to transport particles 3 – 10 cm in diameter [87] and coarser material if sliding or rolling across a hard rock seabed. Currents would tend to be altered under cyclonic conditions, and sediment transport would be enhanced at those times when the surface water gradient between Mermaid Sound and Nickol Bay matched the tidal flow.

ii) Ward et al. [8] made no reference to Flying Foam Passage and made no retrodictions at all for regional or local currents for the period since rising water levels reached 10 m below present [8, their Fig 6].

Thus B2020's argument about weak currents in FF Passage is mistaken and their paper misrepresents the work of Ward et al. [8].

A weak appreciation of sedimentary processes, and especially episodic cyclones, is also apparent in related work [e.g., 19]. The consequence is perhaps most clearly apparent in the consideration of the seabed depression in FF Passage by B2020 and Wiseman et al. [19]. The depression they described is one of a series, with total relief of ~4 m and is ~40 x 80 m in plan view, and with its relatively flat base scattered with cobbles and boulders. B2020 reports that *"One confirmed lithic artefact was located and recorded from the floor of the depression on the final day of the expedition in this area and is typologically comparable in size, shape and manufacturing technique to the*

artefacts from Bruguieres Channel". Both papers wrongly assumed millennia of weak flows in the passage, and B2020 used it to conclude that the artefact was "highly unlikely" [18 p22] to have been derived from the shoreline, 500 m away, or from elsewhere (see also [19 p7 lines 8-12]).

However, as described above, the modern flow evidence alone indicates that this interpretation is not sustainable. Additionally, in the lattermost stages of transgression and early highstand, the entire length of FF Passage will have been subject to strong hydrodynamic forces, whereby any thin soils, vegetation and associated sediments would have first been reworked by waves. Later, once there became a continuous marine connection through the passage, reworking processes would have included strong tidal currents, and wind-driven currents and waves, including during cyclones, which at times would have enhanced the already strong tidal flows. These processes will have contributed to transport of material along the passage floor as well as erosion of the depressions' edges. Thus, depressions now located in the middle section of the passage may have received and accumulated sediments from one or both directions along the passage, as well as downslope from elsewhere, such as eroding adjacent shorelines. Thus, such depressions become a potential sink for mobilised silt-, sand-, gravel-, pebble- and cobble-sized particles, including potential associated cultural material, at least from within FF Passage and perhaps beyond.

Those parts of each depression that are relatively protected from unidirectional flows have potential to form significant secondary sites. Given i) the ample regional availability of sand and gravel (37, 88), ii) its apparent absence from the surveyed depressions (as described by B2020 and [19]), iii) the clear competence of modern processes to transport it through the passage, and iv) the likely ~7000 year history of such processes, we conclude that the cobble and boulder particles noted on the flat parts of the depressions probably represent a lag deposit, with silt, sand and gravel unable to accumulate there. Such depressions in FF Passage are thus prime candidates for investigation, primarily because smaller localised areas within them might be secondary archaeological sites,

having accumulated finer material at times in the ~7000-year period of inundation and particle transport.

2.4. Artefact Analysis and (relative) Dating

2.4.1. Humans as agents of site formation

There is an inherent argument by both D2019 and B2020 that each of the assemblages were spatially and temporally bound, formed as discrete units in one place at one time, and unaffected by activity of later occupants (Table 5). Over a period of 7000 years, a variety of coastal environments will have been associated with the CB channel site, the Dolphin Island site and the FF Passage site, influencing both past human behaviour and also lithic artefact visibility, reuse and recycling [89, 90]. Focussing on historic times, between the 1860s and 1880s, Dolphin Island and FF Passage were part of a pearling industry that extended along the shelf for ~800 km from Barrow Island eastwards to Roebuck Bay, near Broome [91, 92, 93]. Aboriginal people were used as forced labour and were abandoned on the islands in the off-season, and there is already evidence on Barrow Island of such labourers making artefacts [93], so might such a possibility need consideration for the Dampier Archipelago? Did these historic occupants not see or wish to exploit these readily available, large and dense artefact scatters? Similarly, if the interpreted respective early Holocene and late Holocene ages of the offshore and onshore assemblages are correct, then a question rises of why later occupants at both sites might ignore such a dense scatter of artefacts located only tens of metres away in shallow waters. At Dolphin Island, D2019 noted that there appears to have been accessible, easily chosen and readily shaped material on land, in which case reuse and recycling might be less preferred options. However, secondary recycling of archaeological lithic artefacts by contemporary people is a well-recognized phenomenon, including the reuse of ancient stone tools in Australia [90 and references therein]. Given the lack of evidence for age, assessing reuse and recycling appears

vital to correct interpretation, and without more detailed analysis, the true purpose or age (direct or indirect) of any of the documented artefact assemblages remains unknown.

Table 5. Summary of logic used by D2019 and B2020 regarding artefact analysis, with alternative interpretations and suggested methods of testing their assumptions and assertions.

<i>Artefact analysis (D2019 and B2020)</i>					
Used by D2019 and/or B2020	This paper's view		Derived from D2019 and/or B2020	This paper's view	
Explicit assumptions and assertions	Whether and how tested	Did the test provide a clear result?	Uncertainties (U) and Implicit Assumptions (IA)	Alternatives	Example methods that provide a test
-	-	-	IA – Each identified assemblage formed as discrete units each at one time.	Assemblages are not discrete and could have resulted from multiple events [e.g., 90]	Date age of sediments in which artefacts occur. Assess evidence for lithic recycling.
The onshore and offshore artefact assemblages have size distributions that are discrete and meaningful.	Mapped spatial distribution of artefact size ("large" artefacts = 5).	No. No data were shown for the onshore assemblage	U - Unknown variation within the original assemblages and source rocks. IA - Artefact sorting continuous and unidirectional (i.e., seaward). IA - buried artefacts are few and/or not relevant.	Size distribution complex and influenced by local tidal and wave dynamics.	Sample, date and interpret existing sediments and bedforms. Compare with current and wave data. Record artefact size, orientation, plunge. Explore any buried artefacts.
The relative age of the onshore and offshore artefact assemblages can be determined by their "technological differences" (i.e., size) [B2020 p16]	Untested	- (No data were shown for the onshore assemblage)	IA - Previous hierarchical technology [94] valid	Onshore and offshore artefacts are same age.	Assess variation within surface artefact assemblages elsewhere in the region.

Artefact analysis (D2019 and B2020)					
Used by D2019 and/or B2020	This paper's view		Derived from D2019 and/or B2020	This paper's view	
Explicit assumptions and assertions	Whether and how tested	Did the test provide a clear result?	Uncertainties (U) and Implicit Assumptions (IA)	Alternatives	Example methods that provide a test
(B2020) Artefact age is unrelated to age of marine growth	Untested	-	IA – several millennia of marine growth has been removed from artefacts leaving only recent marine growth	Minimum artefact age closer to measured age of marine growth (than to 7000 cal BP)	Date age of sediments in which artefacts occur
Intertidal stone artefacts are not associated with quarrying or animal exploitation (D2019)	Presence or absence of midden sites	Partly	U – Unknown purpose(s) for intertidal stone artefact manufacture	Same assemblage (& purpose) as onshore artefacts	Ethnographic evidence. Residue analysis of stone artefacts.
Stone artefacts are not derived from ballast and are unrelated to historic pearling activities (D2019).	Relative age of artefacts as indicated by differential distribution of historic artefacts.	No, regarding their age	IA - Aboriginal presence in the Dolphin Is. area in the 1860-80's is not relevant.	Artefact assemblage dates to the pearling era.	Ethnographic evidence. Age of concretions on artefacts. Analyse known ballast dump sites regarding abrasion characteristics.
Past occupants ignored any existing artefacts	Untested	-	IA – More recent occupants did not reuse or recycle artefacts	People did reuse or recycle artefacts	Ethnographic and literature-search

633

634

2.4.2. Assessing relative chronology from stone artefact size

B2020 identified two chronologically and technologically distinct lithic assemblages at the CB channel site (Table 5). Those distinctions were based on the comparative sizes between the generally larger (supposed older) channel lithic artefacts, and the generally smaller (supposed younger) beach lithic artefacts [B2020 p16]. B2020 provided only summary and rudimentary descriptions of the “455 artefacts and associated stone structures” [p11] of the onshore assemblage – so it is simply impossible for the reader to assess any of their arguments about the comparisons of “onshore artefacts” with those elsewhere.

B2020 further considered the CB channel intertidal artefacts to be the same age as the Dolphin Island intertidal artefacts, also based on size distinctions [B2020 p23], although D2019 preferentially recorded only the largest intertidal artefacts due to poor visibility in the intertidal zone. In any case, B2020 [p16] claimed “*this size difference is most plausibly explained by technological differences*” and that this explanation was consistent with Lorblanchet and Jones [94] whose midden excavations on the Burrup Peninsula in the 1970s distinguished larger, late-Pleistocene ‘Core Tool and Scraper’ artefacts from smaller, mid-Holocene ‘Small Tool’ artefacts. However, those lithic traditions have largely been discredited [95, 96], and any claims for technologically and chronologically distinct assemblages based on artefact size remain unfounded, including because little is known about the original assemblage variation (Table 5).

Many of B2020’s other arguments for chronological and assemblage differentiation between the onshore and offshore assemblages relate to size-sorting, rounding (polishing) and abrasion and artefact distributions. (Their assessment is based purely on artefact assemblages visible at the surface, and so does not include any buried material, should there be any). Whilst these variables are frequently used to infer water-sorting or reworking of lithic and bone material, each of these may also be influenced by other factors including the nature of the initial artefact assemblage and original source materials [e.g., 97]. Another relevant variable, of artefact orientation and plunge

(e.g., [98]), was not assessed by either D2019 or B2020, but even this might be influenced by the roughness of underlying surfaces and the patchiness of modern sediments at the site as much as by the hydrodynamic regime [99]. In sedimentary terms, artefacts are merely sediment grains, and with the bulk of artefacts at Cape Bruguieres up to 18 cm across [B2020, their Table 2] and maximum typical dimensions of 5–12 cm at Dolphin Island [D2019 p6], the artefacts therefore cover sand-, gravel-, pebble- and cobble-sized grains. This is important because, for example, if the spatial distribution (and rounding and abrasion patterns) of artefacts matched those of the natural grains of similar size, then this might indicate that natural reworking controls their distribution. If on the other hand, artefact distribution is greatly different from natural particles, then other mechanisms, such as human transport, can begin to be considered. Unfortunately, B2020 do not describe nor analyse the presence and patterns of particles of different sizes, within the channel, on the shore terrace or elsewhere in the sedimentary system, so there is no sedimentary framework within which the spatial and size distribution of artefacts can be objectively viewed. This is similar for D2019, who mention the presence of granophyre cobbles but do not document their distribution. For both the Dolphin Is. and CB channel sites, the possibility remains that the onshore and offshore lithic assemblages are of similar age.

2.4.3. Absolute dating and geochemical analyses

The CB artefacts are asserted to be older than 7000 cal BP. A modern age for the CB artefacts would accord with the radiocarbon age of the concretions on some of the submerged artefacts. Further, it must be questioned what process or combination of processes would remove 6500 or more years of marine growth on the submerged artefacts and only leave the most recent growth. No chronological estimates were made for the concretions on the artefact from FF Passage (B2020) or any of those in the Dolphin Island site (D2019), or for the sediments on which they were found. Sediment cores are needed to establish the onshore and offshore stratigraphy, to provide more information around past coastal configurations and sediment dynamics. Having said that, mention was made by [B2020 p23]

of a “*rhyodacite flake recovered by coring, found at a depth of 40 cm below the surface of the alluvial sediment*” at the Dolphin Is. site, indicating that at least some coring was undertaken. B2020 incorrectly referred here to D2019, but presumably meant to refer to the unpublished work of Morrison [70 p38], who described the “*soft, mobile sand*” in cores and suggested that the flake and possible debitage in one of the cores indicates that “*some small artefacts have moved since inundation and have been reworked into the present sand flat deposit.*” Thus, the associated sands remain undated, yet dates are critical to chronological interpretations regarding primary context to establish their age and the stratigraphy.

To apply a relative age to landforms based purely on colour [B2020 p4] is unreliable, because colour depends in part on the nature of the parent rock and iron mineral content [100], and even mature sediments, especially dune sediments, may continue to be reworked [101]. Finally, D2019’s chemical (pXRF) comparisons of artefacts collected from onshore and from intertidal areas are dubious. Not only are a total of five samples statistically insignificant (40 would be a minimum [102]) but analytical penetration depth and attenuation factors [103] were overlooked. The pXRF technique only measures a few microns into the surface of samples [104, 105], hence may have detected residual carbonate on the ‘offshore’ artefacts – and hence higher calcium and strontium values – compared to those measured ‘onshore’.

3. Alternative hypotheses

3.1. Testing the logic of B2020’s three “alternative hypotheses”

B2020 presented three “alternative hypotheses” (p 15) for their “underwater assemblage” sites, broadly covering general options of the assemblage being *in situ*, transported or a lag deposit (their hypotheses a, b and c respectively). Firstly, implicit in the ‘transported’ hypothesis is that if their “underwater assemblage” is a result of transport, it could only have been derived from their “onshore assemblage” that occurs on an adjacent flat terrace “*slightly above Mean High Water*

Springs" [B2020 p9]. Indeed, B2020 (p16) state that for hypotheses (a) and (b), "*evidence against one is by default evidence for the other*". The alternative explanation that the "underwater assemblage" (and indeed the "shore assemblage") might have been transported from elsewhere, was neither considered nor tested. Without a sediment dynamic justification, they B2020 implicitly ruled out that the intertidal artefacts could be derived from the deeper ones, even though the deeper ones are "larger and more massive" (p16). In our view, given i) the 2 m higher water levels at the mid-Holocene highstand, ii) geological and historical storm surges, iii) likely different levels of sediment at the channel site itself and iv) the unknown history of sedimentary control on channel hydrodynamics at key locations to the W and NE, it is wrong for B2020 to implicitly rule out the possibility of wave-driven landward transport of smaller artefacts over the entire ~7000-year period. As noted above (section on Sediment Transport), arguments for the "onshore artefacts" themselves being *in situ* are themselves weak. B2020's overall analysis did not account for modern oceanographic and sedimentary processes, nor, by extension, those possible over the last 7000 years.

Secondly, B2020's hypothesis "c" specified the presence of a "Holocene dune feature, that filled the channel in the final stages of sea-level rise, followed by erosion of the finer sediment fraction by tidal action". Within this hypothesis, B2020 asserted that "it would be necessary to suppose that this beach ridge deposit originally extended continuously along the western shorelines of North Gidley and Cape Bruguieres Islands, blocking the channel that separates them today". The presence of a dune feature is by no means a requirement (see above) and the unnecessary specificity of this hypothesis and its raised importance appears to have resulted in other possible sedimentary deposits (e.g., intertidal, ephemeral) and coastal histories (e.g., a persistently open 'channel') remaining unconsidered and untested (Table 3). Further, human activities and various combinations were not considered or tested. Overall, B2020's "alternative hypotheses" were poorly framed and were not true alternatives – dismissal of two of them does not leave only one possible explanation.

3.2. Potential alternative explanations and further testing

The explanations and possible tests to explore the formation history of the CB and Dolphin Is. sites presented in Tables 2- 5 are not meant to be exhaustive but are intended to help review the logic and arguments for primary context. Regarding the Dolphin Island site, for example, there is a clear absence of any testing to explore the downslope movement of material from the quarry site, to constrain the variables involved and to explore alternative options for movement of material in the intertidal zone. An alternative explanation offered by D2019 [p10] that the artefacts could derive from a deflated dune or beach deposit still warrants consideration. The sedimentary dynamics indicates strongly that at least the intertidal artefacts are likely to be in secondary context.

For the CB channel site, no mention is made of the age and mobility of the significant sand bodies both east and west of the channel site or of sedimentary bedforms within the channel, making it more difficult to justify sediment or artefact mobility or lack thereof. In any case, if the relative ages of B2020 are used, any distribution of artefacts *“consistent with the action of tidal currents or waves”* [B2020 p16] would have been integrated over several thousand years. Dating was largely based on a relative chronology and *“no absolute dating methods or other indicators are available that could further constrain the age of these particular sites beyond the limiting dates and minimum ages presented”* [B2020 p25]. Whilst not available at present, absolute dating of the beach ridges and determination of the marine and coastal stratigraphy will be essential to permit proper examination of the artefacts’ environmental context.

4. Discussion

4.1. Logic and testing options

Our analysis has shown that the interpretation of these artefact scatters as primary context sites by D2019 and B2020 is at best unproven and at worst fatally flawed. B2020 asserted that they paid

“particular attention” to “the taphonomic and depositional histories of the underwater artefacts and their geomorphic context”, yet of the 16 explicit assumptions and assertions (2 oceanographic, 8 geological, 2 sediment transport, 4 analytical) that we identify in the B2020 paper (i.e., a subset of Tables 2-5), only half were tested, and none were tested to a degree that might have produced a clear result. Further, whilst some uncertainties were explicitly noted by D2019 and B2020, many remain untested (Tables 2-5), and there were multiple implicit assumptions that were untested and for which there are reasonable, testable alternatives.

As an example of the consequences of the lack of effective testing, for the B2020 interpretation of the CB channel artefacts to be proven correct would require the artefacts submerged in the channel to have:

- (i) been manufactured and discarded in the depressions in CB channel before 7000 cal BP;
- (ii) been inundated by the sea at ~7000 cal BP;
- (iii) remained exposed on the bed and immobile in the marine environment for at least 7000 years;
- (iv) been undisturbed by humans throughout that entire 7000-year period; and
- (v) only preserved the last few centuries of 7000 years of potential marine growth.

We show that none of these factors were tested effectively by B2020, but for B2020’s claims to be correct, all of these factors need to be true.

Finally, we think it helpful that the status of all coastal and marine artefacts in this region could be considered using a short set of four questions, addressed sequentially. These ask whether it can be ruled out that any or all artefacts could possibly have been moved by:

- Modern hydrodynamic processes?
- Humans, whether in the historic period (~200 years) or by indigenous people at any time?
- Hydrodynamic processes during Holocene highstand?

- Hydrodynamic processes during marine inundation?

Each question would require a specific set of tests to be undertaken. There are 16 unique combinations of results (Fig 12), or 32 if we distinguish the effects of people moving artefacts during the post-inundation period from historic times, which archaeologically is an important distinction. In any case, only one of the possibilities could indicate that the artefacts might be *in situ*. More importantly, the variety of results to these questions would provide valuable information to help improve interpretations of the deposits, and therefore confidence in the inferences about human activities made from them. We expand on this below.

Fig 12 Simplified decision tree when testing the status of coastal artefacts. In such dynamic sedimentary environments such as NW Australia, it is logical that artefacts need to be considered in secondary (2ry) context (red boxes) until proven otherwise, hence only when every potential mechanism of movement can be ruled out might artefacts be considered *in situ* (green box).

4.2. A Secondary Context Resource

It is important to comment on the use of the term “*in situ*”. There are several significant quotes in B2020, including:

- i. *"in the locations where they were originally deposited by human activities on a pre-inundation land surface that predates Holocene sea-level rise", and*
- ii. *"all argue in favour of cultural material that has not substantially moved from its original in situ deposition on a Pleistocene land surface. It is not possible to rule out some slight movement of material, or the possibility that some of the artefacts on the inner margin of the intertidal zone have been displaced from the immediate shore edge, but any such movements appear to have been of very limited extent" and*
- iii. *"the underwater assemblage is largely in situ on a pre-inundation landscape and belongs to a much earlier time period and an entirely different pattern of landscape use than the archaeological site on the calcarenite terrace."*

Therefore, B2020 appear to accept that some movement may have taken place of the artefacts in CB Channel. Logically, if some movement has taken place of large artefacts by natural processes, greater movement would have taken place of smaller artefacts, but B2020 do not consider this option, and most importantly of all, do not consider what this might mean in terms of how the deposits might be interpreted. For example, it would have been possible to identify locations where smaller artefacts might have been deposited, such as near the western opening of CB channel, which would improve interpretations of past human behaviour. Instead, B2020 interpreted size differences as indicative of *"technological differences"* between the artefacts found at the coast and in the channel, and used this as *"further evidence that the underwater assemblage belongs to an earlier time period than the onshore material"*.

In most archaeological work intended to lead to cultural interpretations, the term *in situ* means *"in its original position"* [106] or, in more detail, *"discovered in the place they were last deposited. This means that they have not been disturbed since the point of their deposition. Artifacts which have been moved as a result of either human (ploughing, looting, etc) or natural (faunal, erosion, etc) forces are no longer in situ"* [107]. We think the evidence clearly points to the artefacts in CB channel

and at Dolphin Island being secondary deposits and that the archaeological need is to consider them as such. Finally, one perhaps extreme interpretation of quote i) above is that the artefacts were only *in situ* **before** marine inundation occurred. This make no sense, because it would mean that almost every artefact everywhere is also *in situ*! The entire edifice of archaeology would fall down.

If explored in the context of secondary deposition, the CB channel and Dolphin Island intertidal sites have much to contribute to archaeological theory and specifically formation processes and taphonomy. Whilst lithic scatters, especially chance finds, in the marine environment often do not have precisely known context [108, 109, 110], this does not mean they should be dismissed. Even poorly contextualised sites can provide some ‘intrinsic’ information from individual artefactual and associated environmental data, including assemblage taphonomy and source, artefact recycling, and chronological context [109]. Reworked sites also have clear, unambiguous value as an archaeological secondary context that can be investigated to improve understanding of process and change [34]. This understanding not only relates to past occupation, and ways of “*distinguishing archaeological evidence from pre- and post-inundation time*” [D2019 p3] but also to current site stability and management [111, 112], as well as potential future reworking of the lithic artefacts and site vulnerabilities stemming from impacts of climate change [113]. In passing, we note that it must be addressed how representative individual sites are of their surroundings, especially in terms of constraining their possible contributions to interpretations of regional archaeology. Resolving formation processes in these marine and coastal settings is truly vital.

To progress this, investigations might start with reassessing any ongoing work by D2019 [their p11] for the Dolphin Island site, to include a more comprehensive understanding of site formation and spatio-temporal context, including all secondary sites, whether above or below modern sea level. Hence a key stage in the evaluation of these data is a comprehensive assessment of the physical setting and processes to which components of both the onshore and submerged archaeological assemblages may have been subjected [9, 111, 112]. Oceanographic and sedimentary evidence is a

critical part of this [41], just as on land it is vital to understand soil processes [114, 115, 116, 117]. This assessment must include the impacts of cyclones and other drivers, not just over a single year as per B2020 but over multiple years and simulated over multiple millennia, in concert with potential changes in coastal configuration. The implicit claim by B2020 that such coastal environments in the Dampier Archipelago region should have remained relatively unchanged since before 7000 cal BP is not only highly unlikely but has not yet been tested and thus most certainly has not been demonstrated. Similarly, reference to historical cyclone tracking maps for the region [e.g., 46] clearly show that D2019's [D2019 p9] assumption that the Dolphin Island site has not in the last 150 years (i.e., since pearling) been subject to high-energy events able to transport artefacts is wrong.

4.3. Theoretical contributions of underwater sites – moving beyond finding ‘the first...’

The absence of documented underwater sites on Australia's continental shelf means the impetus to be the first to find and publish on the first or “oldest” marine cultural site is high [118]. However, having such an aim does not constitute adequate research design [1] and further, work risks being exaggerated to support pet theories [119]. As an example, D2019 appears to present a circular argument, seemingly wishing to support an argument that artefact ages are older than the timing of their marine inundation, in their text “*pre-inundation artifact assemblage would support persistent human use of the Dampier Archipelago throughout major environmental changes and over a considerable period—substantiating long-term changes in rock art styles and content*” [D2019 p12].

As always, consideration is required to precisely determine how these sites address larger questions and how our ability to answer these questions is influenced by the formation processes that create the archaeological record and its marine context [9; 120]. As Lemke [1] outlines, submerged prehistory must provide more than just data if it is to contribute to the theoretical side of archaeology or anthropology. So, it doesn't really matter whether a site is supratidal, intertidal, subtidal or fully marine but rather what its contribution is to archaeological understanding. We

876 wonder what these sites tell us that is new or that couldn't be learnt from "terrestrial" sites? Little or
877 no insight is provided by D2019 or B2020 beyond demonstrating the simple fact that such material
878 can survive and can be located, and this is not a new finding, with thousands of UCH sites
879 documented elsewhere in the world (see the references in [1]).

880 Like some others, we worry that current research on this subject is at risk of discovering "more and
881 more about less and less" [121 p4] and may sometimes suffer from "plug and play dementia" [122
882 p34] of which the major defining characteristic is the willingness to fit new information into a pre-
883 existing explanation without evaluating the plausibility of that favoured explanation, and without
884 weighing the likelihood that alternative explanations may be of similar or greater plausibility [122].
885 Unfortunately, this is one view that could be drawn from our analysis.

886 Numerous studies already demonstrate that underwater landscapes can not only preserve evidence
887 of human activity but also the actual record of these changes themselves [1]. The attraction of the
888 CB channel site to humans is argued to be proximity to raw materials before marine inundation, and
889 proximity to marine food resources thereafter [B2020 p21]. Whilst this may well be the case,
890 interpretations of past human behavioural dynamics cannot validate the assumption of primary
891 context. Interpreted behaviours are based heavily, but not exclusively, on the material assemblages
892 found, which themselves are controlled by the processes of site formation and the quality of
893 interpretation of those processes (see also [98]). For both D2019 and B2020, as noted above, many
894 asserted site formation processes are not sedimentologically defensible, yet many of the authors of
895 the B2020 paper themselves published ([12] their Fig 3) that soft rock sites first require an effective
896 assessment of the sediments and the dynamics. Not doing so increases the risks of misinterpretation
897 and that associated interpreted human behaviours might be mistaken.

898 Ultimately, the approach of D2019 and B2020 is essentially inductive, involving the gathering of
899 data, looking for patterns, and developing a theory based on this. It is therefore premature to try to
900 interpret the purpose or activity behind the artefact scatters in both the Dolphin Island [D2019] and

CB [B2020] sites. We emphasise that there is insufficient information to arrive at any firm conclusion, which we acknowledge will be frustrating for the reader hoping that we might provide a solid alternative.

5. Conclusion

"It seems that underwater finds...are held to a different standard of reporting and context, simply for being underwater" [1, p12]

The discovery of prehistoric underwater cultural heritage anywhere is significant. It is therefore especially hard to be a voice of scientific dissent when the world media is promoting the discovery of the "first underwater archaeological sites in Australia" [e.g., 24, 25, 27]. Indeed, such media coverage and related journal publications presenting this claim as fact [19, 20, 21, 22, 23, 31, 32, 33] makes it harder to raise uncertainties or present alternative interpretations to such claims [123]. A "Murujuga 'submerged' stone tool" [sic.] is also on display at the new West Australian state museum in Perth, with the associated label stating specifically, *"When people left these tools behind 7000 years ago, sea levels were lower and the area a dry valley. This find is the first of its kind on the Australian coast..."* yet as noted above, at present there is no actual evidence of the artefacts' ages. There is strong impetus to produce such discoveries, with potential for those discoveries *"focused only on the 'moment of recovery'"* [124] to gain media and scientific attention, and even to be seen by researchers as boosting chances of similar research funding applications made elsewhere. However, we argue there is far greater value to be had in approaching these coastal and marine sites with all the critical elements of a major project, including research questions and logic, appropriate measurements, and defensible interpretations with clear statements of uncertainties (c.f., [125], their section 4-4.5 inclusive, pp. 11-14).

B2020 stated that *"The new results presented here demonstrate the existence of in situ archaeological material on pre-inundation land surfaces associated with periods of lower sea level"*

[18 p2]. Claims of such perceived ground-breaking discoveries, such as those of D2019 and B2020, should require peerless critical thinking, sound research and excellent scholarship [126, 127]. Our analysis has concluded that the interpretation of these artefact scatters as primary context sites is at best unproven and at worst fatally flawed. Further, there was no compelling evidence or argument presented for D2019's and B2020's claims that the "underwater" lithic scatters are distinct from emergent stone artefact scatters on the immediately adjacent shorelines. Of the 16 explicit assumptions and assertions in the B2020 paper, only half were tested, and none to a degree that might have produced a clear result. As noted above, to be proven as *in situ*, the artefacts submerged in the channel would have to have been manufactured and discarded in CB channel before 7000 cal BP, then inundated by the sea, remained immobile on the seabed since then, without any disturbance by humans, and yet only exhibit the last few centuries of potential marine growth. None of these factors were tested effectively by B2020, yet all these factors need to be true. We have offered four reasonable questions (Fig 12) to help determine the status of artefacts found in coastal environments, none of which were or are able to be answered by the evidence presented in D2019 or B2020. Given the numerous geomorphic and chronological uncertainties, incorrect assumptions (e.g., tidal data, tidal flows, coastal stability) and repeated over-interpretations of the data, we are forced to conclude that the key conclusions of D2019 and B2020 cannot be justified. In our view, the work was published (and publicised) far too soon. Moreover, important opportunities to help advance the research field of submerged prehistory were missed. If treated appropriately, these and similar artefact scatters and their associated sediments could provide vital information about past and present physical processes of site formation. There is an onus on all scientists to investigate and interpret archaeological sites objectively and with the greatest credibility possible [126] for the public who fund this research and Traditional Owners who maintain a connection with Sea Country. We hope the suggestions we have provided can help boost

950 the necessary understanding of site formation processes in coastal and marine environments,
951 thereby supporting rigorous archaeological interpretations.

952

Pre-print

6. Acknowledgements

IW and PR were previously employed as a post-doctoral researcher and a PhD candidate respectively on the ARC-funded Deep History of Sea Country project. We thank Steve Buchan of Metocean Consulting for his helpful comments on a draft manuscript. The DHSC is thanked for providing the GIS shapefile of artefact locations for CB Passage, and we thank the Department of Transport of the Western Australian Government for supplying the bathymetric data and images for northern Flying Foam Passage. We thank the journal handling editor for his perceptive and helpful comments and two anonymous referees for their valuable reviews.

7. Author Contributions

IW and PL led and PR contributed to the conceptualisation, formal analysis, writing and editing of all drafts. CF performed the oceanographic simulations, produced the simulation outputs and drafted the Appendix. Figures were made by PR, PL & CF.

8. Supplementary Information – Flow Simulations

We used the well-established Sparse Hydrodynamic Ocean Code (SHOC) model to assess modern tidal currents in the region. SHOC is a state-of-the-art hydrodynamic model developed by CSIRO Marine and Atmospheric Research, begun by Fandry [128, 129] and most recently improved by Herzfeld & Waring [130]. A full list of references is provided by Ward et al. [8].

The SHOC ocean model was run for the period from mid-January to the end of June 2011. In this study, SHOC was setup in a nested configuration with a parent 2500 m grid of 180 x 160 horizontal grid points and 26 layers in the vertical, each with a thickness of 10 m. A smaller 500 m grid of 210 x 140 grid points and 9 layers in the vertical is nested within the parent grid. This configuration provides a sufficiently fine resolution to resolve the many passages within the Dampier Archipelago,

while at the same time covering an area (by the parent grid) sufficiently large to capture the large scale forcing by the winds and tides. The model used a bed roughness of 0.0002 m, and bathymetry is obtained from a variety of sources, mainly Geoscience Australia bathymetric data, which has a horizontal resolution of ~200 m and the GEBCO global bathymetric data at a resolution of 800 m.

The influence of tides is included in the model by forcing the open boundaries of the parent grid, with tidal elevations predicted from the CSR 4.0 global ocean tide model [131, 132]. Tidal constituents included in CSR 4.0 are all the diurnal and semi-diurnal astronomical tides (K1, O1, S1, Q1, P1, M2, S2, N2, NU2, K2, L2, 2N2, MU2 and T2). In a strongly tidally dominated region like the North West Shelf, especially around the Dampier Archipelago, tidal currents easily exceed 1 m/s, and through some of the passages within the Archipelago, tidal currents can exceed 2 m/s.

The flow simulations also included forcing at the ocean surface by ambient (non-cyclonic) wind fields, derived from a global model, the CFSR (Climate Forecast System Reanalysis) [133], which are global modelled winds, calibrated and validated against measured winds globally by multiple organisations, including the Australian Bureau of Meteorology. Wind-forcing can significantly increase tidally driven currents, especially when wind forcing is in the same direction as the tidal currents. The North West Shelf is also subject to tropical cyclones which can produce extreme wind-driven currents. RPS has measured currents in the open ocean on the North West Shelf under tropical cyclones that exceed 2 m/s.

9. References

-
- 1 Lemke A. Submerged prehistory and anthropological archaeology: Do underwater studies contribute to theory? *J. Isl. & Coast. Archaeol.*, 2021; 16(1): 5-26.

-
- 2 Sturt F, Flemming N C, Carabias D, Jöns H, Adams J. The next frontiers in research on submerged prehistoric sites and landscapes on the continental shelf. *Proceedings of the Geologists' Association*, 2018; 129(5): 654-683.
  - 3 Flemming N. Global experience in locating submerged prehistoric sites and their relevance to research on the American continental shelves. *J. Isl. & Coast. Archaeol.* 2020; 16(1), 170-193; Available from: doi.org/10.1080/15564894.2020.1781712
  - 4 Bird MI, Beaman RJ, Condie SA, Cooper A, Ulm S, Veth P. Palaeogeography and voyage modeling indicates early human colonization of Australia was likely from Timor-Roti. *Quat. Sci. Rev.* 2018; 191: 431 -439.
  - 5 O'Connell J F, Allen J, Martin AJ, Williams J, Williams AN, Turney CSM, et al. When did Homo sapiens first reach Southeast Asia and Sahul? *Proc. Nat. Academy Sci.* 2018; 115 (34): 8482–9.
  - 6 Flemming N C. A survey of the late Quaternary landscape of the Cootamundra Shoals, North Australia: A preliminary report. In: Flemming N C, Marchetti F, Stefanon A. editors *Proceedings of the 7th International Diving Science Symposium of CMAS 1983*, Padova, Italy. Padova: Confederation Mondiale des Activites Subaquatiques; 1986. pp. 149–180.
  - 7 Nutley D. Inundated site studies in Australia. In: Evans AM, Flatman JC, Flemming NC editors. *Prehistoric archaeology on the continental shelf: a global review*. New York: Springer; 2014. pp. 255-273.
  - 8 Ward I, Larcombe P, Mulvaney K, Fandry C. The potential for discovery of new submerged archaeological sites near the Dampier Archipelago, Western Australia. *Quaternary International*. 2013; 308–309: 216–229.
  - 9 Ward I, Larcombe P, Veth P. 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. *Geoarchaeology* 2015; 30(1): 19–31.
  - 10 Ward I, Veth P, Manne T. To the islands born: the research potential of submerged landscapes and human habitation sites from the islands of northwestern Australia. In: Harff J, Bailey G, Lüth FL editors, *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, vol. 411. London: Geological Society of London, Special Publications; 2016a. pp. 251-263.
  - 11 Ward I, Larcombe P, Carson A, Lane A. Archaeological assessment of coastal and marine development sites: case study from James Price Point, Western Australia. *Journal of the Royal Society of Western Australia*. 2016b; 99(2): 31–46.
  - 12 Veth P, McDonald J, Ward I, O'Leary M, Beckett E, Benjamin J, et al. A strategy for assessing continuity in terrestrial and maritime landscapes from Murujuga (Dampier Archipelago), North West Shelf, Australia. *J. Isl. and Coast. Archaeol.* 2019; <https://doi.org/10.1080/15564894.2019.1572677>
  - 13 Benjamin J, O'Leary MJ, Ward I, Hacker J, Ulm S, Veth P, Holst M, McDonald J, Ross P, Bailey G. Underwater archaeology and submerged landscapes in western Australia. *Antiquity*. 2018; 92 (363): e10.

-
- 14 Bird C, Hallam SJ. A review of archaeology and rock art in the Dampier Archipelago. Unpublished report National Trust of Australia (WA). 2006. Available from: <https://www.nationaltrust.org.au/wp-content/uploads/2017/01/20061020-Dampier-Rock-Art-Review-ROE35.pdf>
  - 15 McDonald J, Berry M. Murujuga, northwestern Australia: when arid hunter–gatherers became coastal foragers. *J. Isl. and Coast. Archaeol.* 2016; 12: 24–43.
  - 16 McDonald J. Murujuga (Dampier Archipelago) and the journey towards world heritage recognition. *Australian Archaeology* 2018; 84(2): 105-107.
  - 17 Dortch J, Beckett E, Paterson A, McDonald J. Stone artefacts in the intertidal zone, Dampier Archipelago: Evidence for a submerged coastal site in Northwest Australia. *J. Isl. & Coast. Archaeol.* 2019: 1–5. <https://doi.org/10.1080/15564894.2019.1666941>
  - 18 Benjamin J, O’Leary M, McDonald J, Wiseman C, McCarthy J, Beckett E, et al.. Aboriginal artefacts on the continental shelf reveal ancient drowned cultural landscapes in northwest Australia. *Plos One*, 15(7): e0233912. 2020; Available from: <https://doi.org/10.1371/journal.pone.0233912>
  - 19 Wiseman C, O’Leary M, Hacker J, Stankiewicz F, McCarthy J, Beckett E, et al. A multi-scalar approach to marine survey and underwater archaeological site prospection in Murujuga, Western Australia. *Quaternary International*. 2021: 584: 152-170. Available from: <https://doi.org/10.1016/j.quaint.2020.09.005>
  - 20 McDonald J, Beckett E, Hacker J, Morrison P, O’Leary M. Seeing the Landscape: Multiple scales of visualising terrestrial heritage on Rosemary Island (Dampier Archipelago). *Open Quaternary*. 2020: 6 (10): 1-17.
  - 21 Leach J, Wiseman, C, O’Leary M, McDonald J, McCarthy J, Morrison P, Jeffries P, Hacker J, Ulm S, Bailey G, Benjamin J. The integrated cultural landscape of North Gidley Island: Coastal, intertidal and nearshore archaeology in Murujuga (Dampier Archipelago), Western Australia. *Australian Archaeology*. 2021; Available from <https://doi.org/10.1080/03122417.2021.1949085>
  - 22 McCarthy J, Wiseman C, Woo K, Steinberg D, O’Leary M, Wesley D, Brady LM, Ulm S, Benjamin J. Beneath the Top End: A regional assessment of submerged archaeological potential in the Northern Territory, Australia, *Australian Archaeology*. 2021; Available from <http://doi.org/10.1080/03122417.2021.1960248>
  - 23 Hale, J.C., Benjamin, J., Woo, K., Astrup, P.M., McCarthy, J., Hale, N., Stankiewicz, F., Wiseman, C., Skriver, C., Garrison, E., Ulm, S., Bailey, G. Submerged landscapes, marine transgression and underwater shell middens: Comparative analysis of site formation and taphonomy in Europe and North America. 2021; *Quaternary Science Reviews*, 258, <http://doi.org/10.1016/j.quascirev.2021.106867>
  - 24 Bradley, D. Archaeologists find ancient Aboriginal internet sites underwater, off the coastline of Australia. *Newburgh Gazette*. 2020 July 2 [Internet]. Available from <http://newburghgazette.com/2020/07/04/archaeologists-find-ancient-aboriginal-internet-sites/>.
  - 25 France-Press A. Ancient Australian Aboriginal sites discovered underwater. *Jakarta Post*. 2020 July 2 [Internet]. Available from: <https://www.thejakartapost.com/life/2020/07/02/ancient-australian-aboriginal-sites-discovered-underwater.html>

-
- 26 Pinkstone J. Aboriginal stone tools dating back 8,500 years discovered off the coast of Western Australia mark out the sites of two ancient settlements submerged underwater since the last ice age. Daily Mail. 2020 July 2 [Internet]. Available from: <https://www.dailymail.co.uk/sciencetech/article-8479739/First-Aboriginal-sites-discovered-underwater-Australia-date-8-500-years.html>
- 27 Young E. 'Final frontier of Australian archaeology': Drowned artefacts reveal first underwater heritage sites. Sydney Morning Herald. 2020 July 2 [Internet]. Available from: <https://www.smh.com.au/national/final-frontier-of-australian-archaeology-drowned-artefacts-reveal-first-underwater-heritage-sites-20200701-p5586f.html>
- 28 Micheltore, K. Ancient Aboriginal underwater archaeological sites discovered, and a new frontier for study. Australian Broadcasting Corporation. 2020 July 2 [Internet]. Available from: <https://www.abc.net.au/news/2020-07-02/aboriginal-underwater-site-discovered-off-burrup-peninsula/12391858>
- 29 Watson, C. The search for aboriginal history off the coast of Australia. Smithsonian Magazine. 2021 February 3 [Internet]. Available from <https://www.smithsonianmag.com/travel/search-for-aboriginal-history-off-coast-of-australia-180976913/>
- 30 <https://plos.altmetric.com/details/85058510/news>
- 31 Bradshaw CJA, Norman K, Ulm S, Williams AN, Clarkson C, Chadœuf J, Lin SC, Jacobs Z, Roberts RG, Bird MI, Weyrich LS, Haberle SG, O'Connor S, Llamas B, Cohen TJ, Friedrich T, Veth P, Leavesley M, Saltr F. Stochastic models support rapid peopling of Late Pleistocene Sahul, 2021; Nature Communications, 12 (1), <https://doi.org/10.1038/s41467-021-21551-3>
- 32 Crabtree SA, White DA, Bradshaw CJA, Saltr F, Williams AN, Beaman RJ, Bird MI, Ulm S. Landscape rules predict optimal superhighways for the first peopling of Sahul. 2021; Nature Human Behaviour, <https://doi.org/10.1038/s41562-021-01106-8>
- 33 Ditchfield K, Reynen W, Rankenburg K, George AD, Evans NJ, McDonald BJ. The pilot application of geochemical sourcing to an inland Pilbara archaeological landscape in north-western Australia. 2021; Journal of Archaeological Science: Reports, 38: <https://doi.org/10.1016/j.jasrep.2021.103104>
- 34 Hosfield RT, Chambers JC. The Archaeological Potential of Secondary Contexts. English Heritage Project Report (Project No. 3361). London: English Heritage Archive Report. 2004; Available from https://archaeologydataservice.ac.uk/archives/view/apscontexts_eh_2007/overview.cfm
- 35 Wilson B. The Biogeography of the Australian North West Shelf: Environmental change and Life's Response. Burlington, MA: Elsevier; 2013.
- 36 James NP, Bone Y, Kyser TK, Dix GR, Collins L. The importance of changing oceanography in controlling late Quaternary carbonate sedimentation on a high-energy, tropical, oceanic ramp: northwestern Australia. Sedimentology 2004; 51: 1179-1205.
- 37 Semeniuk, V., Chalmer, P.N., Le Provost, I., The marine environments of the Dampier Archipelago. Journal of the Royal Society of Western Australia 1982; 65 (3), 97-114.
- 38 Lewis SE, Sloss CR, Murray-Wallace CV, Woodroffe CD, Smithers SG. Post-glacial sea-level changes around the Australian margin: a review. Quat. Sci. Rev. 2013; 74: 115-138.

-
- 39 Dufois F, Lowe RJ, Branson P, Fearn P. Tropical cyclone-driven sediment dynamics over the Australian North West Shelf. *Journal of Geophysical Research: Oceans* 2017; 122: 225-244.
- 40 Larcombe P, Huang P, Pusey G. From marine geomorphology to turbulence: Some implications of sediment transport for developments on the NW Australian continental margin. Perth: Australian Oil & Gas (AOG). 2014
- 41 Larcombe P, Morrison-Saunders A. Managing marine environments and decision-making requires better application of the physical sedimentary sciences. *Australasian Journal of Environmental Management*. 2017; 24 (2): 200-221.
- 42 Larcombe P, Ward IAK, Whitley T. Physical sedimentary controls on subtropical coastal and shelf sedimentary systems: initial application in conceptual models and computer visualizations to support archaeology. *Geoarchaeology* 2018; 33(6): 661-679.
- 43 Pearce A, Buchan S, Chiffings T, D'Adamo N, Fandry C, Fearn P et al. A review of the oceanography of the Dampier Archipelago, Western Australia. In: Wells FE, Walker DI, Jones DS, editors. *The Marine Flora and Fauna of Dampier, Western Australia*. Perth: Western Australian Museum; 2003. pp. 13-50.
- 44 Eliot M, Influence of Interannual Tidal Modulation on Coastal Flooding Along the Western Australian Coast. *Journal of Geophysical Research: Oceans*, 2010; C11013.
- 45 Forde MJ, 1985. Technical report on suspended matter in Mermaid Sound, Dampier Archipelago. Department of Conservation and Land Management, Western Australia. Bulletin 215, 102 pp.
- 46 Bureau of Meteorology (BoM), Past tropical cyclones. [Internet]; 2020. Available from: <http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/history/>
- 47 Bureau of Meteorology (BOM). Report on Cyclone Orson 1989. [Internet]; 1992. Available from: http://www.bom.gov.au/cyclone/history/pdf/orson_full.pdf
- 48 Nott JF, Hubbert G. Comparisons between topographically surveyed debris lines and modelled inundation levels from severe tropical cyclones Vance and Chris, and their geomorphic impact on the sand coast. *Australian Meteorological Magazine* 2005; 54:187–196.
- 49 Haigh ID, MacPherson LR, Mason MS, Wijeratne EMS, Pattiaratchi, CB, Crompton RP, George S. Estimating present day extreme water level exceedance probabilities around the coastline of Australia: tropical cyclone-induced storm surges. *Climate Dynamics* 2014; 42:139– 157.
- 50 Chappell J. Some effects of cyclonic waves and tidal currents on the coast and continental shelf near Dampier, Western Australia. Unpublished field report, Department of Biogeography and Geomorphology. Australian National University: Canberra. 1982.
- 51 Dodson J, Eliot I, Eliot M, Chagué-Goff C, Goff J. Wrack Line Signatures of High-Magnitude Water-Level Events on the Northwest Australian Coast. *Marine Geology*. 2014; 355: 310 – 317
- 52 Gregson PJ, van Reeken IA. Tsunami observations in Western Australia. In: *Maritime Natural Hazards in the Indian Ocean* (Ed. C.D. Woodroffe), Wollongong Papers on Maritime Policy 6, University of Wollongong, Wollongong, Australia; 1998. pp. 131–145.

-
- 53 Dominey-Howes D. Geological and historical records of tsunami in Australia. *Marine Geology* 2007; 239: 99–123
  - 54 Scheffers SR, Scheffers A, Kelletat D, Bryant EA. The Holocene paleo-tsunami history of West Australia, *Earth and Planetary Science Letters* 2008; 270: 137-146.
  - 55 Burbidge D, Cummins PR. Assessing the threat to Western Australia from tsunami generated by earthquakes along the Sunda Arc. *Natural Hazards*. 2007; 43(3): 319-331
  - 56 Hengesh JV, Dirstein JK, Stanley AJ. Landslide geomorphology along the Exmouth plateau continental margin, North West Shelf, Australia. *Australian Geomechanics* 2013; 48:71-92.
  - 57 May SM, Brill D., Engel M, Scheffers A, Pint A., Opitz S, Wennrich V, Squire P, Kelletat D, Bruckner H. Traces of historical tropical cyclones and tsunamis in the Ashburton Delta (north-west Australia). *Sedimentology* 2015; 62: 1546-1572.
  - 58 May SM, Falvard S, Norpoth M, Pint A, Brill D, Engel M, Scheffers A, Dierick M, Paris R, Squire P, Brückner. H. A Mid-Holocene Candidate Tsunami Deposit from the NW Cape (Western Australia), *Sedimentary Geology* 2016; 332: 40-50.
  - 59 Goff J, Chagué-Goff C. The Australian tsunami database: a review. *Progress in Physical Geography* 2014; 38: 218-40.
  - 60 Goto K, Sugawara D, Ikema S, Miyagi T. Sedimentary processes associated with sand and boulder deposits formed by the 2011 Tohoku-oki tsunami at Sabusawa Island, Japan. *Sedimentary Geology* 2012; 282:188-98.
  - 61 Chagué-Goff C, Schneider J-L, Goff JR, Dominey-Howes D, Strotz L. Expanding the proxy toolkit to help identify past events – lessons from the 2004 Indian Ocean Tsunami and the 2009 South Pacific Tsunami. *Earth-Science Reviews* 2011; 107: 107–122.
  - 62 Goff JR, Chagué-Goff C, Nichol SL, Jaffe B, Dominey-Howes D. Progress in palaeotsunami research. *Sedimentary Geology* 2012; 243–244, 70–88.
  - 63 Ishizawa T, Goto K, Yokoyama Y, Goff J. Dating tsunami deposits: Present knowledge and challenges. *Earth-Science Reviews* 2020; 200: 102971.
  - 64 Prasetya G, Borrero J, de Lange W, Black K, Healy T. Modeling of inundation dynamics on Banda Aceh, Indonesia during the great Sumatra tsunamis, December 26, 2004. *Natural Hazard* 2011; 58: 1029-1055.
  - 65 Foytong P, Ruangrassamee A, Shoji G, Ezura Y. Analysis of Tsunami Flow Velocities during the March 2011 Tohoku, Japan, Tsunami. *Earthquake Spectra*. 2013; 29(S1): S161-S18
  - 66 Ross, P.J. Archaeological Preservation and Feature Identification in Subaerial and Submerged Environments, Dampier Archipelago, WA. Unpublished doctoral thesis, Flinders University of South Australia, Adelaide. 2021.
  - 67 Hill DF. Spatial and Temporal Variability in Tidal Range: Evidence, Causes, and Effects. *Curr. Climate Change Reports* 2016; 2: 232–241.
  - 68 Holloway PE. Tides on the Australian North-west shelf. *Marine and Freshwater Research*. 1983; 34(1): 213-230.

-
- 69 Turner RJ. Beachrock. In Schwartz ML, editor. *Encyclopedia of Coastal Science*. Kluwer Academic Publishers, The Netherlands. 2005. Pp. 183-186.
- 70 Morrison P. The Geoarchaeology of a Submerged Aboriginal Site in the Intertidal Zone of Dolphin Island, Murujuga. Unpublished BA(Hons) Thesis, CRAR+M and Archaeology, University of Western Australia. 2019.
- 71 Semeniuk V, Searle DJ. Beach rock ridges/bands along a high-energy coast in southwestern Australia—their significance and use in coastal history. *J. Coastal Research* 1987; 3(3): 331–342.
- 72 Frankel E. Rate of formation of beachrock. *Earth and Planetary Science Letters*. 1968; 4: 439-440.
- 73 Bird C, Hallam SJ. A review of archaeology and rock art in the Dampier Archipelago, National Trust of Australia (WA). 2006.
- 74 Whitley TG, Berry M, Martinez LC 2018. Visualizing 125,000 years of environmental and landscape change in NW Australia. Available from: [DOI:10.13140/RG.2.2.19934.95042](https://doi.org/10.13140/RG.2.2.19934.95042).
- 75 Dufois, F, Lowe, RJ, Rayson MD, Branson PM. A Numerical Study of Tropical Cyclone-Induced Sediment Dynamics on the Australian North West Shelf. *Journal of Geophysical Research: Oceans*. 2018; 123: 5113-5133.
- 76 Lebrech U, Paumard V, O’Leary MJ, Lang S (2021) Towards a regional high-resolution bathymetry of the North West Shelf of Australia based on Sentinel-2 satellite images, 3D seismic surveys and historical datasets. *Earth System Science Data*. Forthcoming.
- 77 Kenyon, N. H., & Cooper, B. (2005). Sand banks, sand transport and offshore wind farms. *Kenyon MarineGeo*.
- 78 Ashley, G. M. Classification of large-scale subaqueous bedforms; a new look at an old problem. *Journal of Sedimentary Research*. 1990, 60(1): 160-172.
- 79 Department of Transport (2014) Dampier Archipelago – Flying Foam Passage Multibeam / Dynascan Hydrography Survey, Colour coded depths and levels. 7-11 July 2014. Drawing no. 1660-9-2. Government of Western Australia.
- 80 Pandey S and Rao AD. Impact of approach angle of an impinging cyclone on generation of storm surges and its interaction with tides and wind waves. *Journal of Geophysical Research: Oceans*. 2019, 124:7643–7660.
- 81 Geoscience Australia, 2019. DEA Coastlines. Available from <https://cmi.ga.gov.au/data-products/dea/581/dea-coastlines>
- 82 Coastal Engineering Research Center. *Shore Protection Manual*. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg Mississippi. 1984.
- 83 Holloway PE, Nye HC. Leeuwin Current and wind distributions on the southern part of the Australian Northwest Shelf between January 1982 and July 1983. *Australian Journal of Marine and Freshwater Research*. 1985; 36: 123-137.

-
- 84 Physick WL, Blockley A. An evaluation of air quality models for the Pilbara region. CSIRO Division of Atmospheric Research. A Report to the Department of Environmental Protection, Western Australia. 2001; 98pp.
- 85 Clowes A, Comfort P. Process and landform: An outline of contemporary geomorphology. Edinburgh: Oliver & Boyd. 1987.
- 86 Stockmann U, Minasny B, McBratney A. Chapter One - Advances in Agronomy Quantifying Processes of Pedogenesis. In: Sparks DL, editor. Advances in Agronomy, Academic Press. 2011; 113: 1-74.
- 87 Van Rijn LC. Critical movement of large rocks in currents and waves. International Journal of Sediment Research. 2019; 34: 387-398.
- 88 Geofund Pty Ltd, Geophysical Interpretation Report on the Port of Dampier Reconnaissance Geophysical Survey. 1994. Unpublished Report for the Department of Resources Development.
- 89 Camilli E, Ebert JI. Artifact reuse and recycling in continuous surface distributions and implications for interpreting land use patterns. In: Rossignol J, Wandsnider LA, editors. Space, Time and Archaeological Landscapes. Plenum Press, New York. 1992; pp. 113 – 136.
- 90 Coco, E., Holdaway, S, Iovita, R. 2020. The effects of secondary recycling on the technological character of lithic assemblages. Journal of Palaeolithic Archaeology, Available from <https://doi.org/10.1007/s41982-020-00055-4>
- 91 Paterson A. Towards a historical archaeology of Western Australia's Northwest. Australasian Historical Archaeology. 2006; 24: 99–111.
- 92 Mulvaney K. Murujuga at a crossroads: considering the evidence of nineteenth-century contact, Dampier Archipelago, northwest Australia, Australian Archaeology. 2018; 84(3): 248-262.
- 93 Paterson A, Veth P. The point of pearling: Colonial pearl fisheries and the historical translocation of Aboriginal and Asian workers in Australia's Northwest, In : Journal of Anthropological Archaeology. 2020; 57: 101143.
- 94 Lorblanchet M, Jones RM. The first excavations at Dampier (Western Australia), and their place in Australian archaeology (with addendum on radiocarbon dating of Skew Valley midden). Chapter 2, part II. Technical Reports of the Australian Museum online. 2018; 27: 163–190.
- 95 Veth P, Spriggs M, Hiscock P, O'Connor S. Gallus on the crossroads: diffusionist models for Asian artefact 'traditions' in Australia and the last hurrah for cultural evolutionism. The Artefact. 1998; 21:14–18.
- 96 Hiscock P. Archaeology of Ancient Australia. London: Routledge. 2007.
- 97 Domínguez-Rodrigo M, Uribelarrea D, Santonja M, Bunn HT, García-Pérez A, Pérez-González A, Panera J, Rubio-Jara S, Mabulla A, Baquedano A, Yravedra J, Díez-Martín F. Autochthonous anisotropy of archaeological materials by the action of water: experimental and archaeological reassessment of the orientation patterns at the Olduvai sites. J. Archaeological Science. 2014; 41: 44 – 68.

-
- 98 Shackley, ML. The behaviour of artefacts as sedimentary particles in a fluvial environment. *Archaeometry*; 1978; 20(1): 55-61.
- 99 Li L, Lin SC, Peng F, Patania I, Gua J, Wang H, Gao X. Simulating the impact of ground surface morphology on archaeological orientation patterning. *Journal of Archaeological Science* 2021; 26.
- 100 Hennig, P. 2004 Soils. In van Vreeswyk, A M, Leighton, K A, Payne, A L, and Hennig, P, editors *An inventory and condition survey of the Pilbara region, Western Australia*. Department of Agriculture and Food, Western Australia, Perth. Technical Bulletin; 2004; 92, pp. 87-107.
- 101 Ward, IAK, Bateman M, Larcombe P, Scott P, Li T, Murai K, Khan NS, Veth P, Cullen P. A pilot study into the geochronological and geomorphic context for the archaeology of Barrow Island, Western Australia. *Quaternary International* 2021; submitted.
- 102 Shaukat SS, Rae TA, Khan, MA. Impact of sample size on principal component analysis ordination of an environmental data set: Effects on eigenstructure. *Ekologia*. 2016; 35(2): 173 – 190.
- 103 Huntley, J. Taphonomy or Paint Recipe: *In situ* portable x-ray fluorescence analysis of two anthropomorphic motifs from the Woronora Plateau, New South Wales, Australian Archaeology. 2012; 75(1): 78-94.
- 104 Ravansari R, Wilson SC, Tighe M. Portable X-ray fluorescence for environmental assessment of soils: Not just a point and shoot method. *Environment International*. 2020; 134:105250.
- 105 Laperche V, Lemièrre B. Possible Pitfalls in the Analysis of minerals and loose materials by portable XRF, and how to overcome them. *Minerals*. 2021; 11(1):33.
<https://doi.org/10.3390/min11010033>
- 106 Darvill, T. *The Concise Oxford Dictionary of Archaeology* (2 ed.). Oxford University Press. 2009.
- 107 <https://socialsciences.mcmaster.ca/sustainable-archaeology-mcmaster/explore/archaeological-terms>
- 108 Porotov A. Relative sea-level changes and submersion of archaeological sites along the northern shoreline of the Black Sea. *J. Mediterranean Geography*. 2007; 108: 29 – 36.
- 109 Peeters H., Amkreutz L. The Netherlands: Probing into the Submerged Prehistoric Archaeology, Landscapes and Palaeontology of the Dutch Continental Shelf. In Bailey G, editor. *The Archaeology of Europe's Drowned Landscapes*. 2020; pp. 157 – 174.
- 110 Lowery D. 2020. Making the most of chance finds: offshore and inshore. *Archaeology of Eastern North America* 2020; 48: 1 – 22.
- 111 Ward I, Larcombe P, Firth A, Manders M. Practical approaches to management of the prehistoric environment. In Peeters JHM, Cohen KM (Eds) *North Sea Submerged Landscapes and Prehistory. Geology, prehistoric archaeology and research potential of the southern North Sea*. Special issue *Netherlands Journal of Geosciences*. 2014; 93(1-2): 71-82.
- 112 Stewart DJ. Formation processes affecting submerged archaeological sites: An overview. *Geoarchaeology*. 1999; 14(6): 565-587.

-
- 113 Wright, J. Maritime Archaeology and Climate Change: An Invitation. *Journal of Maritime Archaeology*. 2016; 11(3): 255-270.
- 114 Goldberg P, Nash DT, Petraglia DT. Formation Processes in Archaeological Context. *Monographs in World Archaeology*. No. 17. Madison, Prehistory Press; 1993. 188 pp.
- 115 Ward I, Larcombe P. A process-orientated approach to archaeological site formation: application to semi-arid Northern Australia. *Journal of Archaeological Science*. 2003; 30: 1223–1236
- 116 Robins R., Swanson C. Telegraph Poles: The importance of accounting for evidence of absence in archaeological surveys. In: Ulm S, Lilley, I. (eds.) *An Archaeological Life: Papers in Honour of J.Hall*. Research Report Series 7. Aboriginal and Torres Strait Islander Studies Unit. Brisbane, University of Queensland; 2006. pp.73-88.
- 117 Walkington H. Soil science applications in archaeological contexts: A review of key challenges. *Earth-Science Reviews*. 2010; 103: 122–134
- 118 Wallis L. Disrupting paradise: Has Australian archaeology lost its way? *Australian Archaeology*. 2020; Available from: <https://doi.org/10.1080/03122417.2020.1834181>
- 119 Bailey G N. New developments in submerged prehistoric archaeology: An overview. In: Evans A M, Flatman J C, Flemming NC, editors. *Prehistoric archaeology on the continental shelf*. New York, NY: Springer; 2014. pp. 291-300.
- 120 Ward IAK, Larcombe P, Veth P. A New Process-based Model for Wreck Site Formation. *J. Arch. Sci.* 1999; 26: 561–570.
- 121 Allen J, O'Connell JF. A different paradigm for the initial colonisation of Sahul. *Archaeology in Oceania*. 2020 ;55(1):1-4.
- 122 Terrell JE. Show-and-tell genetics: Diagnosis and treatment. *The SAA Archaeological Record*. 2019; 19(1):33-38.
- 123 Tsifti Y, Boomgaarden HG, Strömbäck J, Vliegenthart R, Damstra A, Lindgren A. Causes and consequences of mainstream media dissemination of fake news: literature review and synthesis. *Annals Int. Communication Assoc.* 2020; 44(2): 157-173.
- 124 Gately I, Benjamin J. Archaeology Hijacked: Addressing the Historical Misappropriations of Maritime and Underwater Archaeology. *J Maritime Archaeology*. 2018; 13: 15 – 35.
- 125 Ward I, Larcombe P. Depositional constraints in the use of frequency analysis of radiocarbon datasets for regional models of cultural change: an Australian case study. *Geoarchaeology* 2021; 1-25. Available at <https://doi.org/10.1002/gea.21837>
- 126 Vazire S. Do We Want to Be Credible or Incredible? 2019; [Preprint] Available from: <https://www.psychologicalscience.org/observer/do-we-want-to-be-credible-or-incredible>
- 127 Grimes DR, Bauch CT, Ioannidis JPA. Modelling science trustworthiness under publish or perish pressure. *Royal Society Open Science*, 2017; Available from: [doi: 10.1098/rsos.171511](https://doi.org/10.1098/rsos.171511)

-
- 128** Fandry CB. Development of a numerical model of tidal and wind-driven circulation in Bass Strait. *Marine and Freshwater Research*. 1981; 32:9-29.
- 129** Fandry CB. A numerical model of the wind-driven transient motion in Bass Strait. *Journal of Geophysical Research: Oceans*. 1982; 87: 499-517.
- 130** Herzfeld M, Waring JR. Sparse Hydrodynamic Ocean Code V1. 0 User Manual. 2009. CSIRO Marine Research.
- 131** Cartwright DE, Ray RD. Oceanic tides from Geosat altimetry. *Journal of Geophysical Research: Oceans*. 1990 Mar 15;95(C3):3069-90.
- 132** Eanes RJ, Bettadpur S. The CSR3.0 global ocean tide model: diurnal and semi-diurnal ocean tides from TOPEX/POSEIDON altimetry. The University of Texas Center for Space Research. 1996 Dec.
- 133** National Center for Atmospheric Research Staff (Eds). Last modified 08 Nov 2017. "The Climate Data Guide: Climate Forecast System Reanalysis (CFSR)." Retrieved from <https://climatedataguide.ucar.edu/climate-data/climate-forecast-system-reanalysis-cfsr>.