The Big Flood: Responding to Sea-Level Rise and the Inundated Continental Shelf

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Abstract
Since the first peopling of Australia and New Guinea (the continent of Sahul) during times of lower sea level more than 60,000 years ago, some 2 million km^2 of land, roughly one-third of the present continental land mass, has been drowned by sea-level rise. Landscapes encountered and settled by thousands of generations of people throughout the continent have been inundated by rising seas as polar ice and glaciers melted into the world's oceans. While some archaeological sites formed within these landscapes were no doubt destroyed by the rising seas, many sites are likely to have survived. This submerged archaeological record represents the majority of human occupation in Sahul, spanning the period from initial peopling of the continent to 7,000 years before present (BP). As a major frontier in Australian archaeology, investigation of what is now seabed will ultimately lead to revised and enhanced understanding of the continental archaeological record. By re-evaluating the coastal zone, submerged landscapes, and continental shelf, consideration for these past cultural landscapes in what is now Sea Country has the potential to profoundly re-shape the archaeological discourse of Australia and New Guinea.

Keywords: submerged landscape archaeology, continental shelf, maritime archaeology, marine geophysics, underwater cultural heritage

Introduction

For most of the human history of the continent, mainland Australia was joined to both New Guinea and Tasmania to form the supercontinent of Sahul (Figure 1). Given the scale and duration of low sea-level periods, the known onshore archaeological record dating to the Late Pleistocene and Early Holocene can only be considered to represent the inland components of past settlement. The lack of knowledge of the now submerged archaeological record is problematic because coastal occupation is considered central to understanding hominin dispersal and adaptation across the globe (Bailey et al., 2015; Clarkson et al., 2017; Dillehay 2000; Williams, Ulm, Sapienza, Lewis, & Turney, 2018).

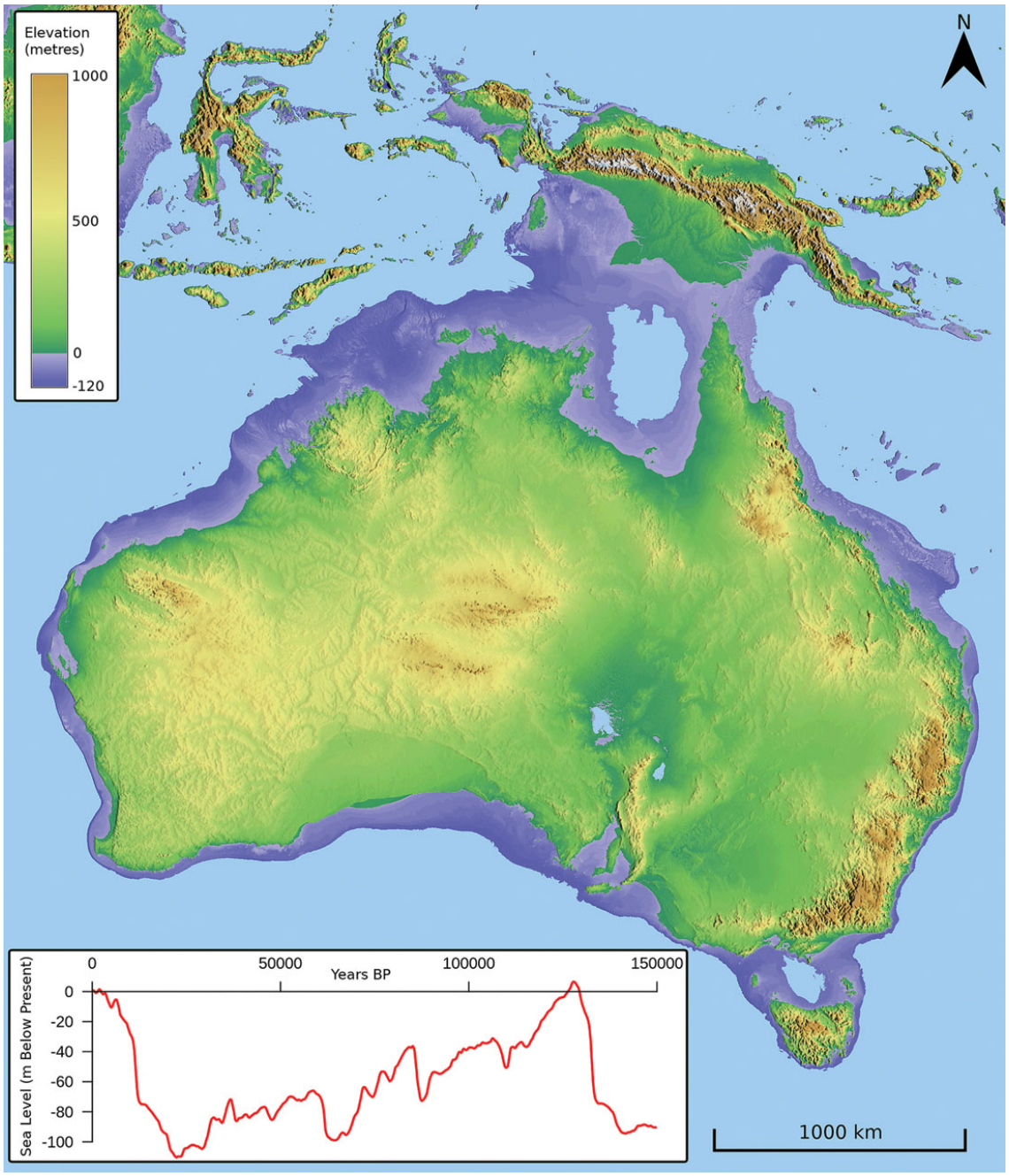

Figure 1. Continent of Sahul with purple showing 2 million square kilometres of land inundated by Late Pleistocene and Early Holocene sea-level rise. Inset shows global sea-level change based on Red Sea deep sea oxygen isotope record (Grant et al., 2012).

A continental archaeological record that ignores the submerged coastal regions lost from view with rising sea levels can only be considered partial and should be viewed with scepticism since coastal populations and landscapes would have been important culturally and environmentally. The exposure of these coastal regions and subsequent inundation by postglacial sea-level rise must have dramatically impacted human lives, cultural traditions and interactions, population densities and dispersals, and social and economic conditions. More data, especially relative to coastal occupation, migration, and cultural adaptation, as well as responses to sea-level changes and lost landmasses is available to archaeologists who are 'willing to get wet' and continue the archaeological search for the human past in what is the next frontier for world archaeology: the marine environment.

It was during the Late and Terminal Pleistocene and Early Holocene when sea levels fluctuated significantly that some of the major transformations of early human history took place. These include large and long-standing questions concerning human dispersals and routes out of Africa into Europe and Asia, and eventually Australia. The development of seafaring technology and diversification and intensification of palaeoeconomies (including marine resources) all took place during these periods (Bird et al. 2019; Fredericksen, Spriggs, & Ambrose 1993; Hawkins et al. 2017; Leavesley & Allen 1998; O'Connor, Ono, & Clarkson 2011; Veth et al. 2017). The exposed landmasses likely included favourable locations for hunter-gatherer settlement and dispersal, and included ample freshwater, desirable microclimates, ecological diversity, and the added value for marine resource exploitation and seaborne travel afforded by these rich palaeocoastlines (Bailey & Flemming 2008; Bailey, Galanidou, Peeters, Jöns, & Mennenga 2020; Bird, Taylor, & Hunt 2005; Faure, Walter, & Grant 2002). These conditions could have supported relatively high population densities and, therefore, high concentrations of archaeological sites as compared to hinterlands. Yet, despite some scepticism about these possibilities (Mellars, Gori, Carr, Soares, & Richards 2013; Petraglia, Breeze, & Groucutt 2019), relatively little is known about the environments of these now-submerged landscapes, the lifeways of their human occupants, their role in patterns of human dispersal and development, or the impact of a sustained sea-level rise from a Last Glacial Maximum low of −130 m at c. 20 ka to reach the present level at c. 7000 cal BP. This dearth of knowledge is now set to change in Australia and indeed World Archaeology in the 21st century (Bailey et al., 2020).

Submerged Landscape Archaeology: International Context

Finding and investigating underwater environments, previously considered to be lost to the world of archaeology, is of global significance and represents a worldwide challenge. In Europe, Western Asia, and North America thousands of submerged ancient sites have been documented, representing drowned cultural landscapes across a range of chronological periods and in various physical environments and depths below modern sea level.

The existence of submerged archaeology, in many cases strikingly well-preserved, clearly demonstrates the potential for survival and recovery of material from under water (Bailey et al. 2020; Benjamin, Bonsall, Pickard, & Fischer 2011; Evans, Flatman, & Flemming 2014; Masters and Flemming 1983) and in some cases can re-shape the archaeological record or demonstrate early examples of human-response to sea-level change (e.g., Galili et al. 2019). Interest in submerged landscape studies was recognised over a century ago. Reid's (1913) seminal publication on *Submerged Forests* was amongst the earliest to insist that attention must be paid to submerged deposits as an archaeological resource. Grahame Clark's (1936) work on the *Mesolithic of Northern Europe* was influenced by the find of a barbed point (the Leman and Ower Harpoon) four years earlier by the crew of the English fishing trawler, *Colinda*.

Throughout the second half of the twentieth century, underwater archaeologists mostly worked locally and in relative isolation, particularly in 'hot spot' regions of the southwest Baltic (Denmark) and Mediterranean Levant (Israel) from the 1970s onwards. In these latter region, diving archaeologists identified known archaeological sites that were visible and accessible in shallow-water conditions. Significant underwater archaeological sites included Tybrind Vig (Andersen 1985) and Atlit Yam (Galili et al. 1993). The work undertaken by archaeologists diving in the Black Sea, particularly the Bulgarian coast, has been perhaps the most overlooked by the international community of scholars, and is itself a significant 'hot spot' that was described by Draganov (1995) and more recently summarised by Peev et al. (2020), with work spanning over four decades.

In North America, submerged sites first began to be discussed amongst the archaeological community in the late 1950s (Garrison & Cook Hale,2021; Goggin 1960), with serious scholarship ensuing in the 1960s and 1970s in the Gulf of Mexico and particularly off the coast of northwest Florida (see Garrison and Cook Hale 2021 for a recent review on the history of submerged landscape studies in North America). The Gulf of Mexico work, such as that highlighted by Anuskiewicz and Dunbar (1993) and Faught and Donoghue (1997), have given rise to serious consideration by the research and heritage management community in North America, which has led to other major projects funded and more community focused work, such as that undertaken by Robinson et al. (2020) and King et al. (2020).

The work in Europe and North America has led to the acknowledgement of the potential for significant submerged sites to make a qualitative impact on the regional archaeological record. This research has highlighted that the preservation conditions of underwater sites is sometimes better than that of terrestrial sites due to relatively stable, cool, and low-oxygen environmental conditions. These regions have also produced local 'models' for site prospection (Fischer 1995; Galili et al. 2018) which articulate the process and theory behind the archaeological search for submerged sites and in situ deposits. Models for site prospection have been critiqued (Grøn, 2018), and evaluated for further, wider international adaptation (Benjamin 2010). In Australia, a national model is not possible, owing to the scale of the issue and the variety of regional challenges and opportunities in the various environmental and cultural landscapes. However, regional models are now coming to light, with lessons learned from overseas and domestic experience (Wiseman et al. 2021).

Sahul Archaeology: Coastal and Submerged Cultural Landscapes

Coasts have long been considered as central to the earliest peopling of the Australian and New Guinea continent. Sahul has never been connected to Sunda, with multiple crossings of up to 100 km required to travel between islands across Wallacea to reach the Australian mainland (Bird, Beaman, Condie, Cooper, Ulm, & Veth 2018; Bird et al. 2019; Kealy, Louys, & O'Connor 2018; Norman et al. 2018). Multiple colonisation events with multiple entry points are likely, with the northwest Australian shelf modelled as the most likely route followed closely by the Bird's Head of west New Guinea (Bird et al. 2019; Bradshaw et al. 2019, in press). Voyaging to Sahul was purposeful with large groups required for successful colonisation, in the order of 1300 to 1550 people (Bradshaw et al. 2019). The earliest landfalls and settlements on the continent are now up to 130 m under water.

Early archaeological sites on precipitous shorelines or on islands close to the edge of the continental shelf indicate that the sea-faring people who peopled Sahul continued to use coastal resources (Allen, Gosden, & White 1989; Codding, O'Connell, & Bird 2014; Fredericksen, Spriggs, & Ambrose 1993; Leavesley et al. 2002; Ulm 2011; Veth et al. 2017). For example,

marine resources are well represented in faunal assemblages from Boodie Cave on Barrow Island off northwest Australia before 42,000 cal BP, with transport distances to the contemporary coastline up to 20 km (Veth et al. 2017). Similarly, in New Ireland in eastern Papua New Guinea, people used a range of coastal resources at the sites of Buang Merabek from 44,000 cal BP and at Matenkupkum from 41,000 cal BP (Leavesley & Allen 1998; Leavesley et al. 2002). All of these data point to the now submerged continental shelves around Australia hosting people over millennia.

Coasts are also considered important in the peopling of the rest of the Sahul continent. Bowdler (1977) argued that the earliest peopling would have been coastally oriented before moving to inland areas. These ideas are given support by recent genetic studies that suggest that people moved rapidly around the east and west coasts of Australia before meeting up in the south of the continent (Tobler et al. 2017). Recent modelling of the movement of people throughout Sahul show the now-submerged continental shelves as important conduits of movement and connectivity, including across the broad plains which once connected northern Australia to New Guinea (Crabtree et al. in press). Some Australian Indigenous oral traditions retain detailed knowledge of drowned cultural landscapes (Nunn & Reid 2016).

With the recent discoveries of submerged sites confirmed along the west coast of Australia (Benjamin et al. 2018, 2020; Wiseman et al. 2021), it is reasonable to conclude that they also exist on the continental shelf around the entire continent and should be a focus for future research. These landscapes include important areas which previously connected now isolated environments, such as the submerged landmass between Australia and New Guinea, as well as the Bass Strait, separating mainland Australia from Tasmania. Further, there are countless smaller islands which were part of the mainland at various periods of human history on the continent. These and the submerged areas that now separate them are currently attracting greater consideration and integrated study through archaeological and marine scientific methods.

Submerged Landscape Archaeology: Evidence from Australia

Historically, there have been relatively few submerged landscape archaeological studies in Australia, and maritime archaeology has focused almost entirely on the archaeology of recent historic periods, especially shipwrecks and maritime infrastructure of colonial and post-colonial eras. The pioneering Cootamundra Shoals survey (Flemming 1982) represented an early attempt to prospect for submerged sites in Australia, some 240 km northwest of Darwin. Flemming's team understood that the shoals represented high ground during periods of lower sea level and were a potential area of interest to investigate the entry by people into Australia. During a month of diving and marine survey, Flemming acknowledged the difficulties and challenges of marine scientific and archaeological work offshore. While greater emphasis on marine and diver-based scientific research has meant more understanding of potential offshore site locations, so too are there more constraints in place today as compared with a generation ago during Flemming's pioneering work. Modern considerations now include greater emphasis on health and safety risks and the increased cost implications, and specialist training and qualifications required by researchers and technical staff. While the archipelago and Cootamundra Shoals would have certainly been home to both faunal and flora that would have provided a pathway to Australia (Bird et al. 2018), no submerged cultural sites were encountered and no artefacts were recorded by Flemming's team. Instead, emphasis was placed on the importance of past landscape reconstruction to inform the survey plan. Nevertheless, this important early attempt to study the submerged landscape highlighted the potential for future studies.

Like Flemming before him, Dortch (1997, 2002) argued the case for investigating the potential for submerged material to be found in both freshwater and marine environments. Dortch (2002) undertook a pilot project in the Dampier Archipelago in Western Australia to locate rock art, specifically petroglyphs, on granophyre outcrops on what is now the seabed. Based on the extensive rock art assemblages found onshore at similar outcrops, Dortch (2002) established a basic model of where material existed and in locations that he thought would be conducive to the survival of sea-level transgressions. Dortch also considered the potential archaeology of the local area: lithic scatters, quarry sites, and material embedded in indurated carbonate deposits. Unlike Flemming's work, Dortch concluded that future surveys should deploy a comparatively modest, shore-based approach. His concerns, that locating rock art in the marine environment did not warrant the expenditure of a large sea-going expedition, is understandable. Marine work, particularly in the offshore environment can be costly. As Bailey (2014) noted, archaeologists should take some care to avoid repeated failure that could lead to disinterest or dismissal by the wider community. The possibility of chance finds in the archipelago, frequented by sports divers, was also emphasised by Dortch, which is in line with many of the international models, such as those practiced in the hotspots of Denmark and Israel (see Benjamin 2010; Fischer 1995; Galili et al. 2019).

Nutley has undertaken multiple reviews of the state of research in studies of inundated Indigenous sites in Australia, first as part of his graduate studies (Nutley 2005) and later to assess the preservation scenarios for various types of material culture frequently encountered in Australia, including shell middens, carved trees, bora rings, fish traps, stone artefacts, rock outcrops, rockshelters, and rock art (Nutley 2014). Nutley noted that fish traps, rocky outcrops, and caves or rock shelters remain relatively stable and are less likely to be impacted by marine transgressions than exposed, open air sites, such as those found in Denmark. He therefore highlighted these as higher potential features for prospection (Nutley, Coroneos, & Wheeler 2016). Nutley (2014) also noted a previous lack of engagement and future need for Australian archaeology to continue submerged landscape research despite previous attempts and, until that point, a lack of positive results. The criteria outlined by Nutley (2014) represent an important phase of identifying preservation conditions in known examples to move towards the unknown since little work had been undertaken, and no confirmed offshore underwater sites had been discovered.

Other surveys, generally working in the intertidal zone, such as the studies in Cygnet Bay Tasmania (Lewczak & Wilby 2010), Flying Foam Passage Western Australia (Dortch, Beckett, Paterson, & McDonald in press), McNiven (2004) in northeastern Australia, and Ulm (2006) in central Queensland, have documented archaeological material on coastal fringes within the intertidal zone. These sites demonstrate the importance of the intertidal zones. These are areas where material encountered may be indicative of further, deeper water sites, formed prior to relative stabilisation (usually between c. 7000 and 5500 years ago, with other considerations for isostatic and tectonic adjustment). The intertidal zones in micro-tidal environments are smaller, whereas areas with larger tidal movements can provide other challenges in preservation and operational considerations for diver or snorkel survey. These intertidal zones, noted by Dortch (2002), should be the starting point for archaeological surveys, particularly those operating on smaller budgets, prior to pushing the archaeological boundaries offshore.

During the Deep History of Sea Country (DHSC) project, undertaken in collaboration with the Murujuga Aboriginal Corporation, submerged archaeological material was discovered through an iterative program of fieldwork in the Dampier Archipelago, Murujuga, Western Australia (Benjamin et al. 2020; Veth et al. 2020) (Figure 2). The DHSC team built on domestic and

international work cited above, by developing an iterative process and predictive model for site location that considered the onshore archaeological record, satellite and aerial data collection and interpretation, and geophysical surveys of seabed in search for conducive conditions for site visibility and preservation. Hot spots and high potential areas were then targeting and tested through snorkeller and diver investigations, with two new sites recorded below the low water mark and various other intertidal finds located around the archipelago. These new submerged sites include in situ lithic assemblages associated with submerged palaeochannels and freshwater billabongs, clearly demonstrating past human presence on a now drowned land surface. These discoveries demonstrate the potential and viability of underwater archaeological research in Australia and resulted in recommendations for a long-term strategy and the growth of a new research community to tackle the large and diverse coastal and marine environments flanking the Australian continent (Figure 3).

Methodologically, the DHSC project showed that through interdisciplinary marine/geoarchaeological methods and a suite of regional and site-scale methods, it is possible to identify high priority areas for diver-based investigation to produce archaeologically positive findspots and confirm the presence of underwater sites. While the Dampier Archipelago (Murujuga) was selected for its archaeologically rich cultural landscape, there is a strong likelihood of encountering archaeology offshore in a variety of conditions represented by Australia's continental shelf.

Figure 2. Divers investigate the seabed and record lithic artefacts at Cape Bruguieres during the DHSC Project fieldwork (Photographs: S. Wright; see Benjamin et al., 2020).

Figure 3. Marine geophysical work can be complex and time consuming, but invaluable to underpin locations for diving prospection (Photo: J. Benjamin).

Discussion and Future Directions

In the past decade archaeological interest has increasingly focused on the 20 million km^2 of land that would have been available, even favourable, for human occupation during the low sea-level of the Last Glacial Period across the globe. Exposure of this enormous scale of prior cultural landscapes and subsequent drowning by postglacial sea-level rise would have dramatically impacted global patterns of human population dispersal, cultural change and adaptations, and socio-economic development. Archaeological evidence from underwater sites is critical to understanding these important processes that have helped define human history. The discovery of in situ lithic assemblages on Western Australia's continental shelf demonstrates past human use of a now-drowned land surface – it is a proof of concept that should change the face of archaeological practice as it represents the offshore extension of the terrestrial archaeological record. In New Guinea, the uplifted Bobongara terraces with archaeological material dating to at least 40,000 and perhaps as early as 60,000 years ago provide additional contexts for investigating areas of the seabed that are now dry land (Groube, Chappell, Muke, & Price 1986). Investigating and understanding this record in partnership with Indigenous traditional owners and custodians presents one of the last frontiers in the archaeology of Australia and New Guinea and one with enormous potential. The findings reported by the DHSC project, building on past work, demonstrate that underwater cultural material can survive inundation by sea-level rise in an Australian context, and that it can be located and studied using a combination of predictive modelling and an appropriate suite of underwater and remote-sensing techniques. The ambiguities over the depositional status of artefacts found in shallow water close to the present-day shoreline can be resolved through conventional archaeological and geoarchaeological analysis. In addition, evaluation of site formation hypotheses taking account of known and identifiable processes of coastal disturbance and change can help chronologically constrain seabed sites, as was the case at Cape

Bruguieres where a limiting date of pre-inundation (c. 7000 cal BP) was ascribed (Benjamin et al. 2020). However, the sites found in the Dampier Archipelago could be older and further study is required to better reconcile the ages of those findings.

While Holocene material is only likely to be found in shallow waters (i.e., <20 m below Mean Sea Level (MSL)), Pleistocene material is likely to be present in both shallow and deeper water as well as further offshore. Material from the Last Glacial Maximum may be located as deep as 130 m below current MSL. The combination of techniques and evidence trialled by the various projects cited above provides a baseline for features that could be preserved and identified through marine survey techniques. As such, we encourage future scholars working in Indigenous Archaeology to push the boundaries of coastal archaeology and to integrate offshore areas. Similarly, or perhaps conversely, we encourage those working in the more traditional field of Maritime Archaeology to train in and prepare for archaeological encounters and discoveries of all types and periods. This preparation may require greater understanding of flaked stone technology, or more consideration for the archaeological signature of older or more ephemeral features beyond shipwrecks or maritime installations. The recent results by the DHSC project represent a first step and only by continuing along these lines will archaeology in Australia realise the potential of the vast and formerly productive continental shelves. Notably, the initial discovery of lithics on the now-submerged Pleistocene land surface of Cape Bruguieres channel were by John McCarthy and Chelsea Wiseman, two doctoral candidates from Flinders University who had been trained in submerged sites in Europe and the Middle East. That is, both archaeologists had previously encountered lithics in the marine environment and were able to transfer that skillset to an Australian context. However, there is now greater potential for training in Australia as submerged archaeology is no longer hypothetical. There is also a current need to consider these recent findings and their impact on the management and protection of submerged Indigenous heritage in sub-tidal jurisdictions. As we move from 'potential' to the 'confirmed' presence of submerged underwater cultural heritage in Australia, a much more robust discourse, involving government, industry, researchers, and Traditional Owners and custodians, becomes increasingly inevitable.

Archaeology of submerged environments spanning from the intertidal zone to deep water down to -130 m below modern sea levels will contribute to the archaeology of Australia and New Guinea in two main ways. Firstly, these data will fill in some of the nearshore gaps where coastal sites seem to end at the waterline. It is highly probable that nearshore shallow water sites will be found if appropriate investigations are undertaken as part of research projects or development-led archaeological investigations. Second, deeper water sites, particularly those encountered further offshore with continental shelves extending hundreds of kilometres, will provide evidence about large regions of the continent that remain entirely unknown. Knowledge of these areas will be vital for characterising the diversity of lifeways of people across vast swathes of space and time in Sahul.

In the wake of international and recent studies there is an opportunity to create a community of practice for submerged landscape archaeology in Australia. However, a single Australian Model is unrealistic, unlike in Denmark and Israel. The continental scope and scale, variety and complexity of Sahul is diverse and complex. Models may develop, though they will be most useful at the regional or local scale. The size of the continent and its associated environmental diversity means that there are too many variables for a single approach beyond the coarsest detail that relates to the two simple facts for all submerged archaeology: site formation and site preservation. Add to the equation the requirement for archaeological visibility and recognisability by archaeologists (or someone willing to inform a local

archaeologist) and a generalised, coarse-scale model can be considered at a national level; though this model is but a mere starting point for more precise, regional or local investigations and methodologies. The methods tested in the Dampier Archipelago may be relevant to the Pilbara coast, but only partially helpful in assessing areas that differ considerably in terms of environmental conditions. At a minimum, methods applied in Western Australia would require some level of adaptation. As an example, a sub-bottom profiler was not used on the sediment-starved shelf, as stratified sedimentary deposits in the Dampier Archipelago are rare and this type of seismic survey would likely contribute little useful information. However, in other seabed contexts of Australia where previously terrestrial land surfaces (palaeosols) might be preserved, the application of sub-bottom profiler systems would be useful, particularly when coupled with other techniques such as a multibeam echosounder and geotechnical coring (see Astrup et al. 2020; Garriso, 1992; Missiaen, Pieters, Maes, Kruiver, De Maeyer, & Seys 2017; Tizzard, Bicket, Benjamin, & De Loecker 2014). A combined approach to reconstruct past coastal environments and establish priority locations, as applied overseas, will support higher probability for archaeological material to be encountered by diver or drop-camera surveys.

Conclusion

We can now draw on both domestic and international experience to underpin the next generation of underwater cultural heritage management and submerged archaeological research practice in Australia and New Guinea. However, allowing a mature submerged landscape sub-discipline of archaeology to form and realise its full potential will require a new generation of scholars, students, practitioners, and interested and engaged community members who can work with industry, policy makers, and Traditional Owners and custodians. Results from remote sensing during the DHSC project have numerous methodological implications. The evaluation of how effective the terrestrial analogy can be in determining priority study areas for submerged landscape archaeology has both pros and cons. While known terrestrial sites on land and in intertidal zones will likely lead to more discoveries, it is also important to remember that models can generate a self-fulfilling prophecy; finding sites you expect to be there can perpetuate research bias. Rather, there is also a need for exploratory, blue-skies surveys, in areas where evidence is likely to produce new, and possibly exciting data that are unpredictable, and which varies from the terrestrial record. Such research is potentially costly, which is why underwater cultural heritage management needs to collaborate with industry which collects seabed data for other purposes. Indeed, industry undertaking environmental pre-disturbance seabed surveys or monitoring will undoubtedly be important in the coming century of research in the marine environment.

The search from onshore to offshore should be continued. This strategy was demonstrably effective at Cape Bruguieres Channel where archaeological material could be found at the water's edge, and dive teams were therefore able to follow the material into the marine environment. Terrestrial analogy as applied here is a useful contributing framework to identify prospective areas, and in the case of Cape Bruguieres Channel, has proved effective in locating archaeological material. However, preservation characteristics and post-depositional processes remain a significant factor. The combination of remote sensing, ground-truthing, and geological sampling is particularly important in determining the impact of formation and erosional processes over time, in conjunction with the application of terrestrial analogues. Thus, a multi-pronged, multi-scalar approach to survey in both the nearshore shallows and deeper offshore environments which considers environmental and cultural variables must be encouraged for the potential of submerged landscape archaeology to be realised in the twenty-first Century.

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