METHOD

Seeing the Landscape: Multiple Scales of Visualising Terrestrial Heritage on Rosemary Island (Dampier Archipelago)

Jo McDonald[*], Emma Beckett[*], Jorg Hacker[†,‡], Patrick Morrison[*] and Michael O'Leary[§]

The Dampier Archipelago (Murujuga) is on Australia's National Heritage List because of its significant rock art and numerous stone structures. When people first started living in this arid landscape of the north-west coast, 50,000 years ago, the shoreline was 160 kilometres further north-and west. The Archipelago was created around 7,000 years ago, with sea-level rise following the termination of the Last Glacial Maximum (LGM). Photogrammetry and microphotography (using LiDAR, RPA and Dino-Lite™) are used here to demonstrate how this combination of different scales of imaging can be used to better document the terrestrial Murujuga features record. This paper explores the utility of photogrammetry generated by LiDAR and RPA to locate and reconstruct two types of Aboriginal stone structure (standing stones and house structures) which are prevalent across the Archipelago. These combined techniques were deployed to better visualise and understand site distribution with a view to using the landscape scale methods for the detection of similar features in submerged contexts in the adjacent waters. It has been predicted that this more robust site type would be likely to survive being submerged by sea level rise, and hence this was a site type which we were interested in locating remotely. As well as undertaking systematic terrestrial survey and recording of sample areas across Rosemary Island, topographic LiDAR was flown on two occasions (2017, 2018). These flights were separated by a wildfire which burnt most of the spinifex cover across the island. It highlights the potential – and shortcomings – of remote sensing this type of cultural sites in a naturally rocky and spinifex-covered landscape. It makes recommendations about how to better implement LiDAR to assist in the understanding of the landscape context of these hunter-gatherer stone features.

Keywords: Rock art; Stone structures; Photogrammetry; LiDAR reconstruction; Murujuga

Introduction

The culturally and scientifically significant terrestrial and marine environments of the National Heritage Listed Dampier Archipelago, north-western Western Australia, have been the research focus of two Australian Research Council projects: The *Murujuga: Dynamics of the Dreaming* (MLP) and *Deep History of Sea Country* (DHSC). The MLP was focused on systematic survey and recording of terrestrial landscapes to understand how and when people produced art, and changed their use of these places, through time. The DHSC project was a multi-disciplinary study designed to investigate the potential for submerged cultural heritage within the Archipelago. In order to gain a better understanding of the association between landform and archaeological site types, both these projects took advantage of a suite of airborne remote and geophysical survey techniques to investigate, at multiple scales, marine and terrestrial landscapes of the Archipelago.

The archaeological record from nearby Barrow Island (**Figure 1**) indicates that people have occupied the Abydos coastal plain since at least 50,000 years ago (Veth et al. 2014), and there are now ten sites in the Pilbara and Western Desert occupied between 40–50,000 years ago (e.g. Dortch et al. 2019a; Morse et al. 2018). We know that Murujuga was occupied during the LGM (McDonald et al. 2018), and recent archaeological investigations of Murujuga's islands indicate that people were fairly intensively occupying these landscapes by the Late Pleistocene-Early Holocene transition (e.g. Dortch et al. 2019b; McDonald and Berry 2016). A primary objective for both research projects was to understand how the land- and seascapes evolved and with this the evidence for human occupation. This paper explores the utility of some of the innovative approaches used by MLP and DHSC archaeologists, geomorphologists

* Centre for Rock Art Research and Management, School of Social Sciences, Archaeology, The University of Western Australia, WA, AU

† ARA—Airborne Research Australia, Salisbury South, SA, AU

‡ College of Science and Engineering, Flinders University, Bedford Park, SA, AU

§ School of Earth Science Sciences, University of Western Australia, WA, AU

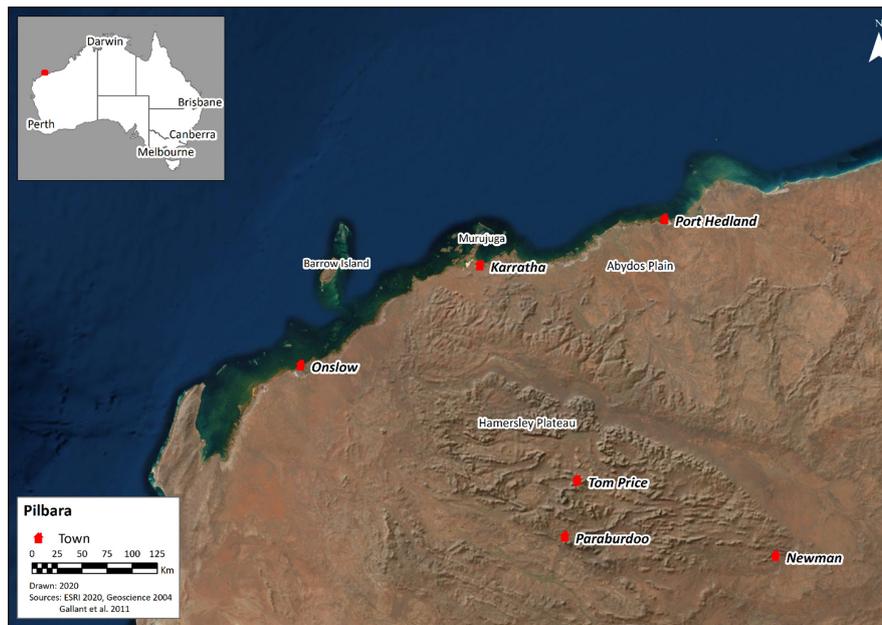Corresponding author: Jo McDonald (jo.mcdonald@uwa.edu.au)

Figure 1: Murujuga (the Dampier Archipelago) in its regional context, showing locations/sites named in the text (ESRI 2020; Geoscience 2004; Gallant et al. 2011).

Figure 2: Location of field survey areas and visualisations. ESRI 2020 and Western Australian Land Information Authority (WALIA).

and remote sensing scientists to first characterise the broader landscape and then detect Aboriginal cultural features within these landscapes. For this study, a combination of predictive modelling (McDonald 2015; Veth et al. 2019) with these different scalar geophysical and visualisation approaches was aimed at focussing on terrestrial landscapes, with a view to determining whether such features could be identified in submerged contexts (Benjamin et al. 2019). We have predicted that the stone features which are ubiquitous across the Murujuga landscapes are one of the site types which would be expected to preserve in a submerged context as the sea levels rose (Veth et al. 2019). This paper explores whether LiDAR might be expected to be the correct technique for prospecting for this site type in submerged contexts.

For this paper we focus on Rosemary Island which is one of the Archipelago's outermost islands, and one of the first landscapes to have been reached (circa 8,500 years BP) and cut-off by post-glacial sea-level rise (after 7,000 years BP). As well as excavating prospective geomorphic locations (e.g. McDonald and Berry 2016), the MLP focused on rock art and stone features and recorded over 500 engraving (petroglyph) and stone feature sites on this one island alone (see **Figures 2** and **3** and McDonald et al. in prep).

Given the high density of GPS located and recorded stone features on Rosemary Island, we investigated the potential of remote sensing including (1) air photo, (2) Remotely Piloted Aircraft (RPA) imagery, and (3) LiDAR point clouds to identify these known terrestrial sites.
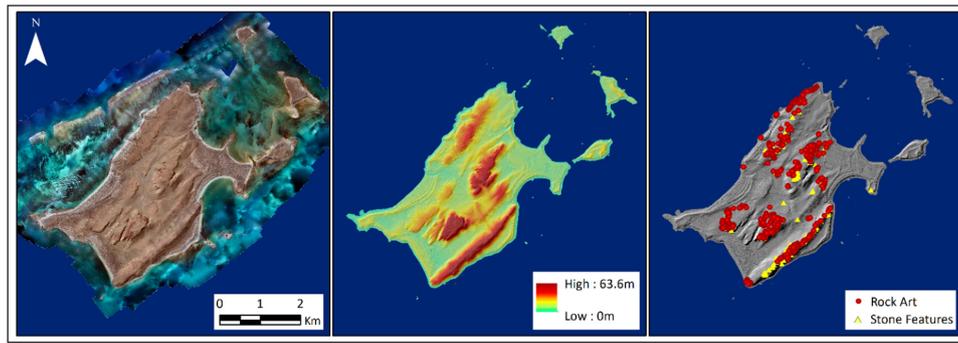
Figure 3: Rosemary Island RGB imagery from ARA motorglider (left); a digital elevation model (DEM) created from LiDAR (middle); and hillshade created from DEM showing the distribution of recorded art panels and stone features across the island (right).
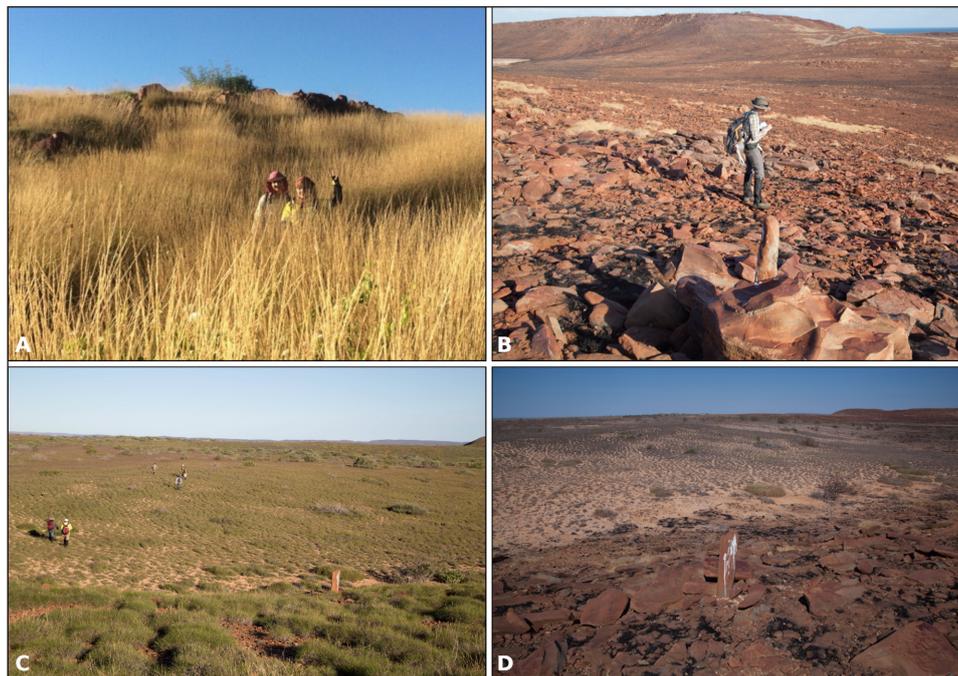

Figure 4: Examples of spinifex before and after the 2018 Rosemary Island fires showing (top, **A** and **B**) changed visibility conditions during survey (bottom **C** and **D**) view of the same standing stone in RA02 in its landscape context. CRAR+M MLP photos.

Airborne high-resolution topographic LiDAR has been used to create digital terrain models on spatial scales of 100s of metres to 10s of kilometres at pixel sizes of 10–20 cm. Such digital terrain models have demonstrated with great success a number of significant new cultural finds, particularly within built landscapes in heavily vegetated landscapes in South America (Canuto et al. 2018) and Cambodia (Evans 2016) and agricultural systems in Vanuatu (Bedford et al. 2018). LiDAR has been used with success in Australia on rock-constructed fish traps on intertidal flats (Emmitt et al. 2020; Kreij et al. 2018). This paper examines the utility of LiDAR to locate, map and display hunter-gatherer archaeological sites, specifically stone features that involve arrangements of single to multiple stones. We focus on individual cultural sites, where we have also used aerial imagery collected by a range of remotely piloted aircraft (RPA) to derive very high resolution (sub-cm pixel sizes) RGB-imagery and photogrammetry-derived digital surface models (DSM) to successfully map the stone features. It is not efficient (in terms of data volumes/image processing) or practical (due to flight time and line of site flight limitations) to use RPA technology to locate and map features over large areas (e.g. Rosemary Island is 5 km north-south by 5 km east-west). Therefore, we compare site-scale RPA elevation models with the landscape-scale models derived from the high-resolution topographic LiDAR to establish the utility of this method to detect archaeological sites over much larger survey areas. The achievable pixel sizes and point densities of high-resolution airborne topographic LiDAR can allow the detection of anthropogenic landscape features over larger areas (see Bedford et al. 2018). In the Dampier Archipelago, however, there are anthropogenic features that are not large, at the landscape scale, combined with a background landscape that is massive and rocky. The vegetation here also proves a complicating factor as dense spinifex vegetation covers many of the Archipelago's landscapes (**Figure 4**), effectively masking the ground surface and making the

identification of stone arrangements significantly more challenging (see Walsh et al. 2016).

In traditional human-managed landscapes, spinifex is burnt and mosaic burning results in a vegetation regime that encourages animal hunting (Crabtree et al. 2019). This is demonstrated in Australia's Western Desert where regular firing of the spinifex (*Triodia spp.*) savannah increases the richness of plant species, decreases the potential for devastatingly large wildfires, and has an important impact on faunal populations (Bird et al. 2005). There has been no fire management of this kind on the outer islands of the Archipelago for centuries (Morris 1990: 39). Indeed, Department of Biodiversity Conservation and Land Management (DBCA) personnel suggested in conversation with one of the authors (McDonald, pers. comm., 2016) that there had been no managed firing of the outer Islands for over 35 years (because there is minimal property there and their fire-management responsibilities are focused elsewhere, e.g. on the industrial estates of the Burrup).

The biggest impact that this has on archaeological detection is that spinifex growth is extreme (in some places we observed this to be several metres tall), and this obscures ground features as well as impeding pedestrian survey. The other problem is that some human stone features consist of a circular arrangement of rocks of several metres in diameter, in essence, a similar circular morphology (i.e., shape and vertical extent) to the torus (or "donut") growth forms of aging spinifex (Burrows et al. 2014), with both features co-occurring in the same environment.

Our initial attempts to use LiDAR data in a predictive way proved challenging as the observed circular spinifex growth forms and the human circular stone constructions which we had recorded during ground-based survey appeared visually similar in the point cloud generated Digital Elevation Model (DEM): hence our interest in this methodological challenge. A large fire, ignited by a lightning strike, burnt much of Rosemary Island at the start of 2018. This provided an opportunity to undertake a second LiDAR mapping campaign over the island and directly compare the pre and post burnt point cloud data and make a direct assessment on the degree to which spinifex masks the ground surface. We demonstrated in our 2018 field season that surface survey and recording was significantly easier with an absence of spinifex (see **Figure 4**).

Methods
Sentinel-2
Analysis of Sentinel-2 Data involved acquisition of pre burn (10/05/2017) and post burn (10/05/2018) Sentinel-2 multispectral satellite imagery, which was analysed in ArcMap 10.5 (see **Figure 5**). Band 2 with a central wavelength of 490 μm (blue spectrum) was found to show the greatest contrast difference between burnt and unburnt areas, and also has a pixel resolution of 10 m. Pre-burn and post-burn Band 2 greyscale imagery was compared using the raster calculator function in ArcMap with the difference in spectral intensity of each overlapping pixel subtracted so light (unburnt) and dark (burnt) showing the greatest contrast and therefore difference.

LiDAR Data collection
The DHSC project deployed one of the Airborne Research Australia's (ARA) motorgliders over Rosemary Island fitted with two airborne small-footprint full-waveform resolving LiDARs: Riegl Q680i-S (topographic) and Riegl VQ-820-G (topo-bathymetric) and an RGB-camera (Canon EOS 5 Mk4). In 2017 (25th Sep and 1st Oct; pre-burn), 48 flight lines covered the island and surrounding waters. On the 22nd May 2018 (post-burn) 30 flight lines covered the same areas again.

The primary purpose of the DHSC LiDAR flights was capturing the bathymetry of the near shore waters in the Dampier Archipelago. Both topographic and bathymetric LiDARs were operated at all times which required flying at a nominal altitude of 600 m above ground or water to ensure eye-safety (i.e. from the bathymetric laser beams). For best spatial resolution (point density/spacing) of the point clouds from the topographic LiDAR, a lower flying height would have been desirable, as well as to fly denser spaced survey lines. Given the scope of the flights across the broader Archipelago, more focused LiDAR was not possible.

The resulting point density/spacing for individual lines is typically 20–25 points/sqm (22–20 cm spacing). As some of the lines were flown twice and as there
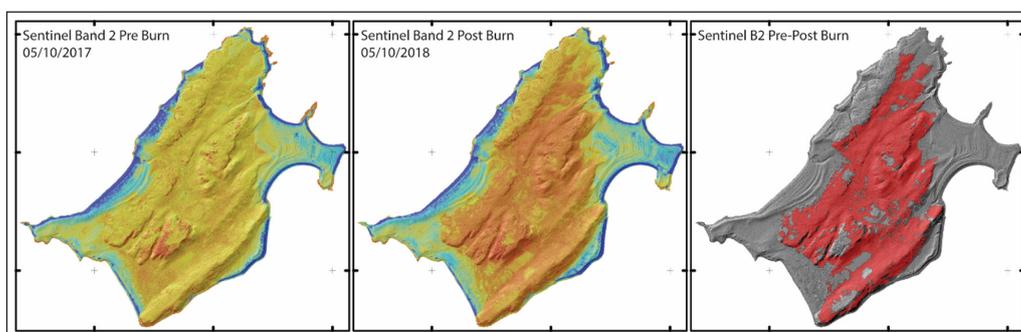

Figure 5: Sentinel-2 imagery of Rosemary Island pre and post fire areas. Left and central panel showing Band 2 spectral reflectance from low (blue colour) to high (red colour). The red areas in the central panel represents areas that have lost their covering vegetation resulting in higher reflectance values of exposed rocks. The greatest contrast difference between the left and central panels represent loss of vegetation as a result of the bushfire and highlighted in red on the right panel.

is considerable overlap, somewhat higher point densities were achieved after aligning and combining the point clouds from the different lines. The average pixel size for the RGB-images is 12–14 cm.

LiDAR pointcloud classification tools with optimised parameter settings were used to distinguish between different surface features. For the first study reported here, the focus was on trying to separate spinifex bushes (low veg) in the LiDAR from rocks (ground). The challenge here was the density of the spinifex clumps, which are so compact and extensive that in most cases the LiDAR cannot see through them to the ground. Classification algorithms using vertical differences in the last returns (i.e. vegetation height vs. ground height) or relying on horizontal surfaces (i.e., ground being flatter than vegetation) alone performed poorly in this environment. The best classification algorithm accessible to the authors was the ones offered in Riegl's RiAnalyze Software (Version 7.0) which also uses the pulse width, the vertical spacing of the pulses along the same laser shot and the distance to neighbouring shots. In this paper, the Riegl default values for these parameters were used. For all results displayed in this paper, either the Riegl classification was used or the return number of the discreet returns, or a combination of both.

RPA data collection and photogrammetry
Photogrammetry was created in a number of locations and here we compare several examples where we have both close range aerial and terrestrial capture techniques (see the five identified features identified in red in **Figure 2**). Two different collection techniques focused on capturing imagery as either an object centred or landscape centred scene, which has scale implication for the outcomes.

1. **Object centred** scenes were created by isolated transects collecting convergent oblique images. Imagery was taken from a range of heights and angles but focusing on a central area (or 'object') of interest. Both terrestrial (Canon EOS 5D Mark III with 22MP) and low altitude aerial (Inspire II Pro using a DJI FC350 with 12MP camera) images were used. Reconstructions of isolated stone structures (often parts of a larger site complex) and the platform upon which the *Connecticut* whaling inscription was placed employed this technique (see below).
2. **Landscape centred** scenes were created by flying systematic overlapping transects between 20–50 m above ground. Data was collected using two different RPAs, a custom octocopter (18 MP Canon EoS-M DSLR camera; piloted by Nik Callow, UWA) and DJI Mavic Pro quadcopter (using the standard 12.35 MP DJI FC220). Most of the imagery presented here (RIA02-2017-DF010, RIA02-2017-DF012-01, Rosemary 8 and RIA03-2018-EF030) was created from a landscape centred approach flown in 2018 by Emma Becket.

All photogrammetry workflows included importing images into Agisoft Metashape 1.4.5 where they were aligned and converted into a dense point cloud. Sparse point clouds were filtered for modelling landscapes with cleared/stacked structures (points were removed using reconstruction uncertainty and projection accuracy filters). In landscapes with standing stones, sparse point clouds were not filtered as the process removes these stones from the model. The resulting dense clouds contained <1 cm spacing and were used to create a range of outputs including; a Digital Surface Model (DSM), orthorectified (ortho) imagery and a 3D polygonal mesh. All ortho imagery created has very high resolution with a ground sample distance (GSD) of less than 1 cm.

Photogrammetric models have good local (relative) accuracy (cm), however as models rely on the internal GPS of the cameras (generally accurate to between 3–5 m), global (absolute) accuracy also tends to be between 3–5 m horizontal. Photogrammetric data can be georeferenced to the more globally accurate LiDAR data to allow for comparison between the two datasets. This process is a straightforward shift on the horizontal (x/y) axes. The vertical (z) axis tends to be less accurate as models are affected by radial distortion increases in areas of steeply sloping ground. This issue does not affect the comparisons presented as they focus on areas of more level terrain. When georeferenced the internal accuracy of the photogrammetric models were shown to be comparable to the LiDAR data.

Dino-Lite™
A Dino-Lite™ hand held digital microscope was used in the field to examine engravings for micro analysis. The Dino-Lite™ was connected to a field laptop and allowed for the magnification of engravings up to 200×. The locations of areas analysed using this technique were mapped, and focused on intersections of the earlier Aboriginal and later metal engraved lines (see Paterson et al. 2019 for detail).

Results
Identification of fire-affected areas
Three methods were used to identify and visualise the fire-affected areas on Rosemary Island:

1. imagery from the Sentinel-2 satellite;
2. visual interpretation of the RGB-image mosaics from 2018; and
3. the airborne topographic LiDAR data.

Figure 5 shows the results of analysis of method (1) the imagery from the Sentinel-2 satellite.

Method (2) compares the aerial RGB mosaics from the pre- and post-burn flights. The mosaics were generated using Agisoft Metashape and have pixel sizes of 14 cm (see **Figure 6**).

For method (3), all returns were used to generate a 20 cm pixel size DEM for each year and then the two DEMs were subtracted from each other. A comparison of the burnt areas as derived by the three methods is shown (**Figure 7**).

Stone features
The MLP has recorded 344 structures in the six sample areas across Rosemary Island (**Figure 8**). For our purposes here, these fall into two broad groups: single stones and
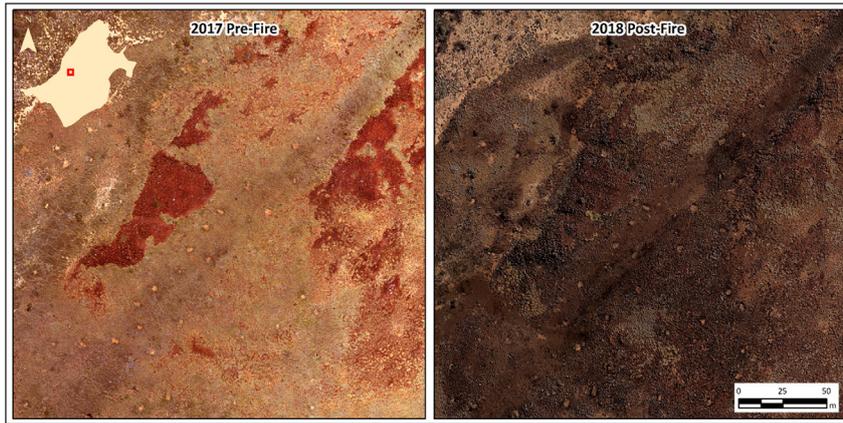
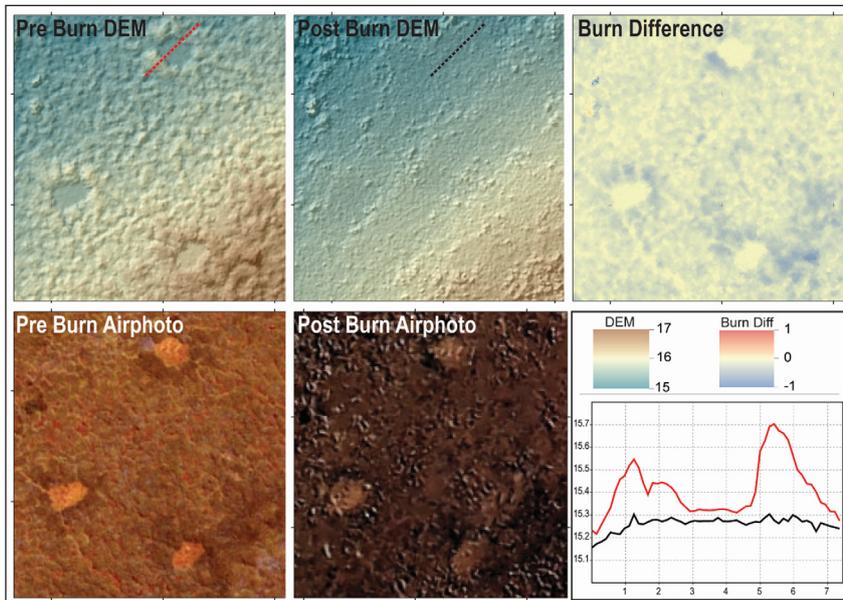**Figure 6:** Pre- (left) and post-burn (right) RGB mosaics of aerial imagery.

Figure 7: Pre and Post Burn aerial imagery and LiDAR derived DEM (10 cm resolution). Burn Difference was calculated by subtracting the Post Burn DEM elevation from the Pre Burn DEM. The negative values in the Burn Difference is the result of is the loss of elevation though the burning of spinifex. This is illustrated in the pre (red line) and post (black line) burn cross sectional profile spanning a single circular spinifex feature.
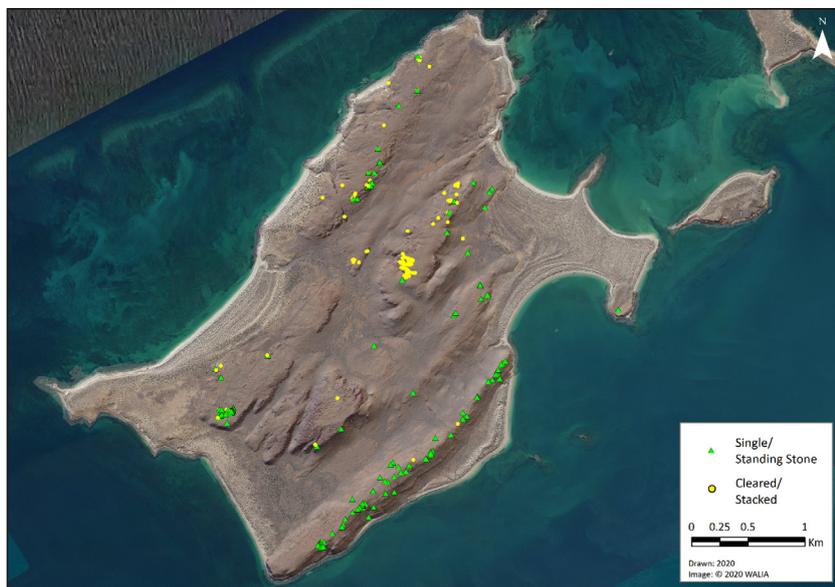
Figure 8: Distribution of stone structures across Rosemary Island (Airphoto © 2020 WALIA).

cleared/stacked features. Single stones (primarily standing stones) generally make up about 60% (n = 204) of the structures identified on Rosemary Island. Standing stones are upright stones wedged or chocked in place: these tend to be 30–70 cm in height and are 10–60 cm in width (median width is 23 cm). Many of these stones show additional human interactions, including engravings or flaking (see **Figure 9**).

Cleared/stacked features comprise 40% (n = 140) of recorded stone structures on Rosemary Island. These include a wide range of structures that have been created by stacking stones to create walls or piles (**Figure 10**). The
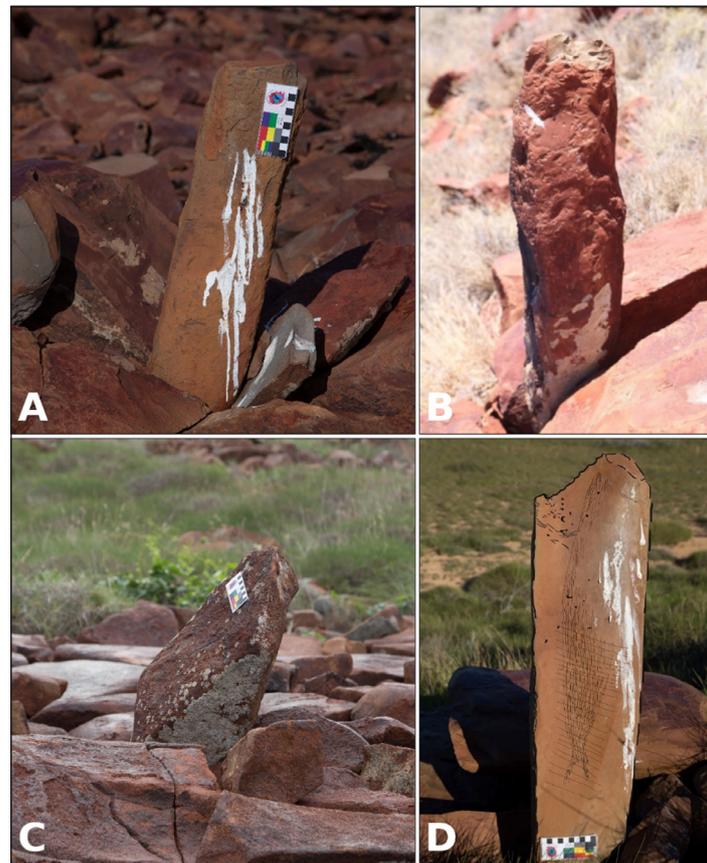
Figure 9: A) Chocked standing stone (RIA3-2018- EF012); **B)** Wedged and Flaked Standing Stone (RIA3-2018-EF026); **C)** Standing Stone (RIA4-2016-BF041); **D)** Engraved Standing Stone (RIA01-2016-BF015 – fish in a net engraving traced using the graphics editor application for iPAD, ProCreate®).

Figure 10: A) Cleared area creating circular enclosures (RIA2-2017-DF010); **B)** circular stacked structure (RIA2-2017-DF012); **C)** linear pile of stones with two standing stones (RIA3-2018-EF030); **D)** cleared/stacked stones creating circular features (RIA4-2018-EF01-02). Structure excavated in 2014 (McDonald and Berry, 2016 Figure 4, photo: Paul Bourke).

removal of stones to build these positive relief structures also creates associated negative relief ditches and shallow clearings or depressions. These structures have been grouped together because the signature in the RPA/LiDAR data is similar across these types (and see Walsh et al. 2018). The RPA/LiDAR data primarily picks up the areas of clustered stones as a distinct change in relief, regardless of whether the change is created by removal or addition of stones.

Visualising archaeological features in a landscape context

Over 92 individual standing stones have been identified along a 3 km ridgeline, which was recorded as Sample Area 3 (SA3: **Figures 2** and **8**). Almost 500 m of the southern end of the ridgeline was not surveyed so it is likely that there are well over 100 stone features in this landscape. There is generally less than 50 m distance between standing stones along the SA3 ridgeline, which means there is often another such stone visible from any one location that has a standing stones (see below). The size of each individual stones as well as the scale of the 3 km ridgeline means that it is difficult to reconstruct and visualise the nature and extent of standing stones across this whole area. Viewshed analysis could be used to investigate this spatial arrangement, but in this instance would be redundant because of the stone features' proximity to each other.

The LiDAR point cloud spacing (20 to 22 cm) is too large for what is needed to classify the presence or absence of standing stones in an exploratory sense. Even when the location of standing stones are known, if a LiDAR pulse hits the top or side of a standing stone the point will appear as a single floating point above the ground and can be potentially or mistakenly classed as background noise. The density of points in the photogrammetry point-cloud varies depending upon the method used and the camera. To assess the viability of landscape centred drone imagery, using a commercial RPA a 130 × 130 m area was flown (**Figure 11**, top left) along part of this ridgeline. The flight used a landscape centred approach with a linear transect pattern and flight altitude of 20 m (frontlap 80% and sidelap 75%). The sparse point cloud was unfiltered and a 3D triangular mesh was built from the dense point cloud (High Accuracy) and textured using the original images. The resulting point spacing was finer (<1 cm) than the LiDAR and standing stones are visible, though still not very clearly. This is likely to be in part due to image quality achieved by the Mavic Pro camera as well as the additional noise created by the spinifex growing around these structures (which was not burned during the wildfire in 2018).

When RPA imagery containing standing stones is converted into a 3D model, again, stones are visible but not well reconstructed. **Figure 11** shows a range of factors that make 3D modelling of these structures more difficult. These include the difficulties created by spinifex (**Figure 11A**), which also creates additional noise in the point cloud. The piled structure is visible but is obscured by the spinifex (**Figure 11B**). **Figure 11C** and **11D** show how difficult it is to clearly visualise the standing stones in this landscape. Note that the green arrows on **Figure 11D** indicate the actual location of the standing stones.
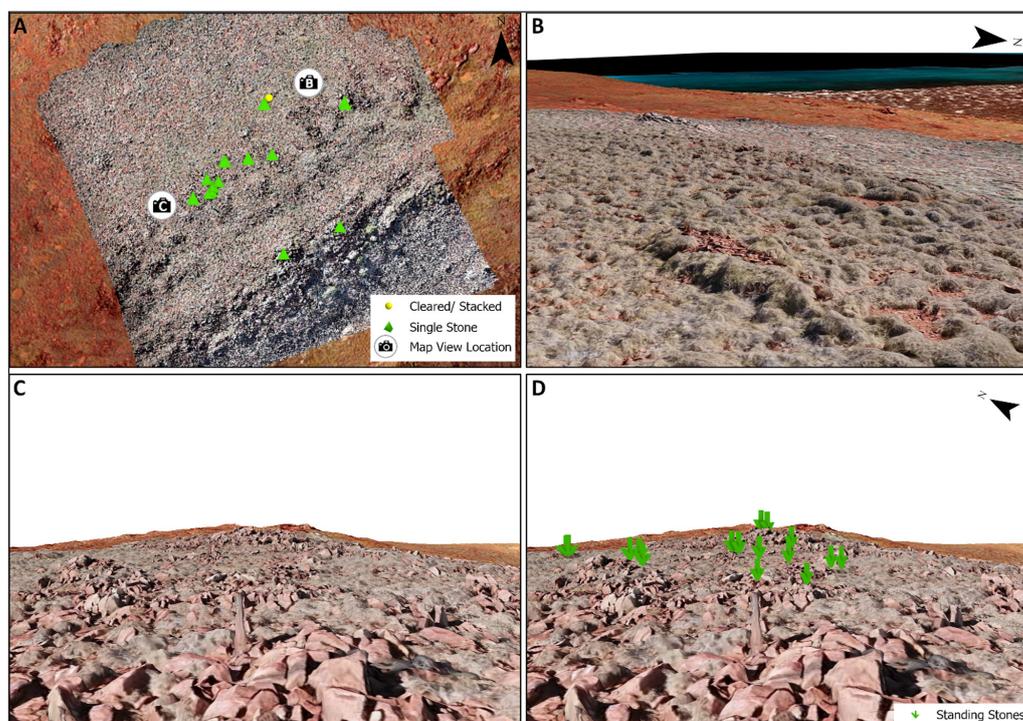

Figure 11: 3D Models built from RPA imagery on the sampled A3 Ridgeline showing how spinifex obscures structure visibility and creates difficulties in producing a clean mesh **A)** Overview showing locations of stone features and the location of camera for B and C/D. **B)** Linear stacked structure obscured by spinifex. **C)** Group of standing stones. **D)** Same group of standing stones with locations of stones illustrated with green arrows.

Despite the difficulties in prospecting the location of standing stones using either airborne LiDAR or aerial RPA imaging, when standing stones that have been dGPS and GPS mapped during fieldwork are overlayed on a high resolution LiDAR-derived DEM, this provides a powerful tool for visualising the landscape context of the standing stones (**Figure 12**). The association, position and density of standing stones on their landscape context provides not only an opportunity to theorise and/or make interpretations on the cultural purpose or utility of these features:

· From where can these features be seen? The sea below (i.e. do these post-date islandisation)? Or are they interior landscape markers, potentially demonstrating increased territorial marking behaviour, perhaps as the coastal plain diminished at the end of the Pleistocene (see McDonald and Berry 2016)?
· How do these structures relate to both art production and the extensive stone tool quarrying of the fine-grained volcanoclastic bedrock along this ridgeline?

It also provides data that can be used in a predictive model for the underwater prospection of such Aboriginal cultural heritage items should such a similar drowned ridgeline be located.

RPAs down to micro analysis

The SA3 ridgeline overlooks an interior passage, looking towards Malus Island: a perfect vantage point for observing whales. Amongst the numerous stone features and rock art panels of SA3, the MLP project found an inscription that is amongst the only archaeological evidence for American whalers landing on Australia's northwest coast before the establishment of a colonial presence (Paterson et al. 2019). The inscription was made on August 18th

1842 by crewmember Jacob Anderson from the American Whaler *Connecticut* that sailed from New London a year earlier. Jacob Anderson and Captain David Crockett's names have been superimposed over the top of two earlier Aboriginal grid motifs, marking a moment of very early historic culture contact in Murujuga's inscribed land- and seascape. The relationship between the inscription and the Aboriginal art motifs were demonstrated by systematic use of the digital microscope to capture the intersection of these sets of stone-made and metal-made marks (Paterson et al. 2019: 221, 224, **Figure 5**). Visualising this place in the landscape involved the use of a range of different photogrammetric techniques at a variety of scales.

We used a combination of RPA, handheld DSLR, and microscopic imagery (using a Dino-Lite™) to record and visualise the inscription, to understand not just the inscription itself, but the landscape context of its siting and the microscopic elements necessary to interpret the inscription event. The RPA imagery was collected using an object centred methodology and was reconstructed using Agisoft Metashape to produce a landscape-level model, a model of the boulder, as well as a high-resolution model of the inscription itself. These were then rectified by manually selecting assigning markers in Agisoft Metashape and linking them hierarchically. The LiDAR and aerial photogrammetry were used to rectify the RPA imagery, which was then used to rectify the boulder model, and then the inscription. This produced a georeferenced model at multiple scales, which we made into a narrated visualisation (Morrison and McDonald 2019; https://youtu.be/ANtpNDfmeXo) to accompany a The Conversation article (McDonald et al. 2019). Another version was produced for use in a PowerPoint presentation. The strength of this 3D output is the visualisation can be rapidly modified to suit different presentation formats or purposes.
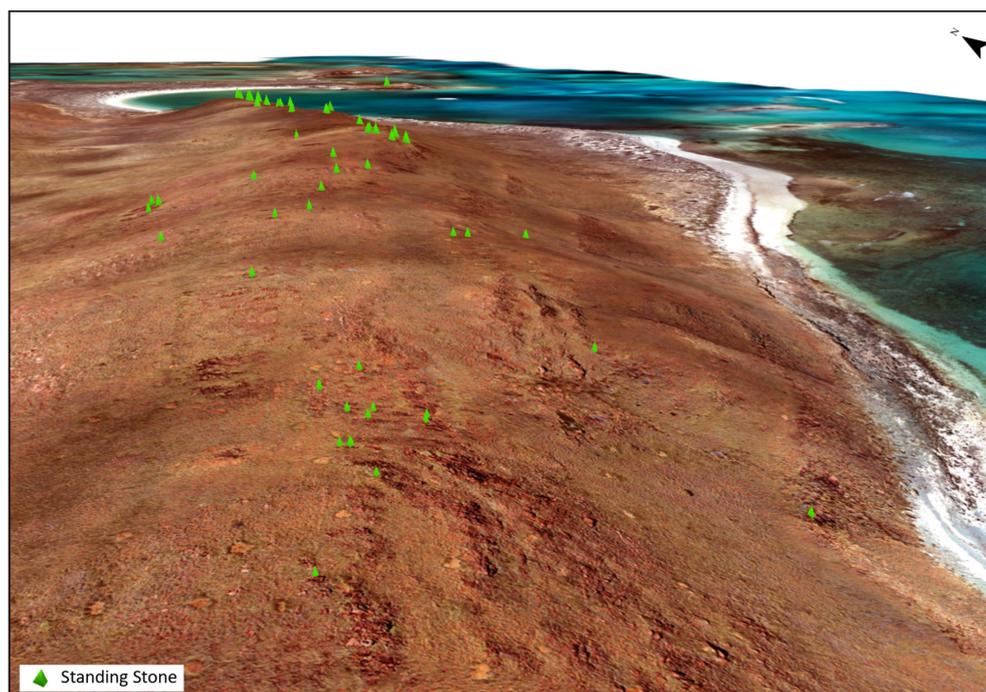

Figure 12: Visualisation of the A3 Ridgeline looking north with locations of standing stones plotted.

The final visualisation was produced using the free and open source Blender 2.8 Beta 3D software (Blender Online Community 2019; **Figure 13**). All models were imported, and a camera move was used to zoom in through the different scales. D-Stretch image enhancement (see Harman nd; Harman 2011) was useful for a clearer reading of the inscription, but this processing degrades the imagery. D-Stretch was integrated into the visualisation using a custom material node setup, which animated the enhancement, enabling an authentic understanding of the original surface, while also being able to visualise accurately the inscription.

Finally, Dino-Lite™ microscopic images were imported as flat planes, and manually positioned on the surface, coupled with another material node set up to visually highlight key the engraving marks (**Figure 14**). At this scale of analysis, it was possible to visualise clearly how the whaler's metal tool marks, possibly made with a scrimshaw tool (Dyer 2018), overlay those from the Aboriginal artist's stone tool. In the future, a series of microscopic images could be taken with the purpose of photogrammetry in mind, which would enable a seamless 3D reconstruction of microscopic details, but the approach used here shows it is possible to retrofit any imagery into a 3D environment.
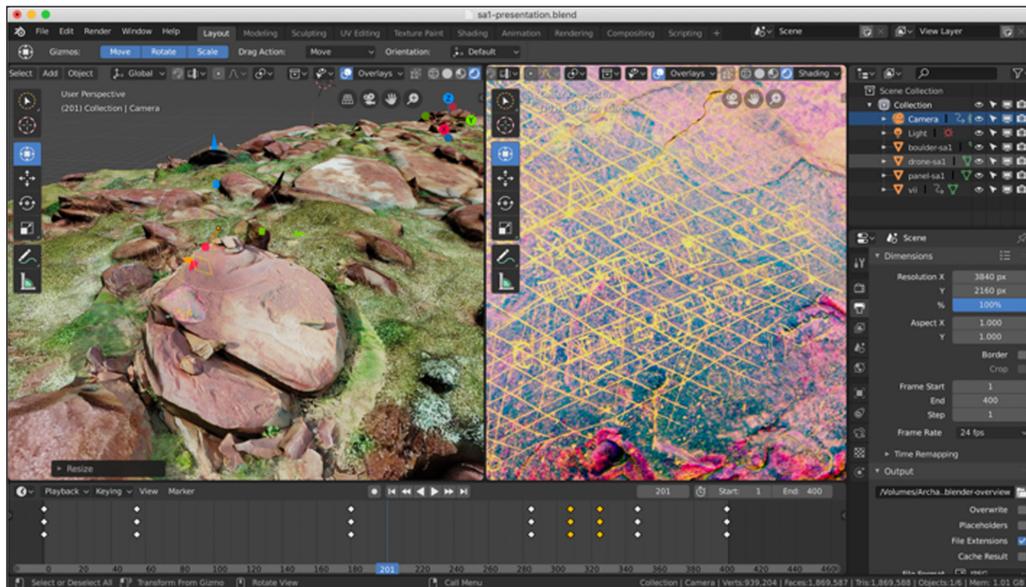
Figure 13: The Connecticut Inscription model in the Blender 3D package, showing the boulder and the camera view of the inscription with D-stretch enhancement.

Figure 14: Microscopic detail in the Connecticut Inscription, showing the Dino-Lite™ image placed on the surface. The overlay shows more clearly the superimposed tool marks.

Visualising stone features at the site level: Rosemary 8
The Rosemary 8 site complex includes 63 stone structures (**Figure 15**) in a very different landscape context to those found in SA3. Most (n = 54; 86%) of these structures are again standing stones, but here the gabbro geology has weathered to form six horizontal platforms with loose surface blocks of various dimensions and shapes, which have been used in the modified stone structures. Spinifex only grows between these platforms, meaning visualisation here presents a different challenge, but making it significantly easier to create a useful model (**Figure 16**). This site contains the densest concentration of standing stones on the island (34 standing stones on Platform 6 in an area of 180 m²).

The methods used for these two different landscape views was identical (linear transect pattern a height of 20m, frontlap 80% and sidelap 75% with a Mavic Pro).

The absence of spinifex, the underlying horizontal platform structure and the more upright angle of the stones at this site allowed the 3D mesh to be built using the height field (as opposed to the 'Arbitrary' default). This creates a blocky appearance in some stones but overall provides a cleaner and clearer model. As with **Figures 11** and **12** LiDAR and ortho image created from the on board camera provide some additional background. Both types of technology (LiDAR and RPA) are useful for creating realistic interpretations of these features.

Ultimately, the best way of visualising standing stones in a 3D environment is when the photographs were taken using an object centred approach, particularly focusing on one standing stone (see **Figure 17**). The sheer quantity of these structures at sites like this, makes this a far more time-intensive task than with landscape-level approaches.
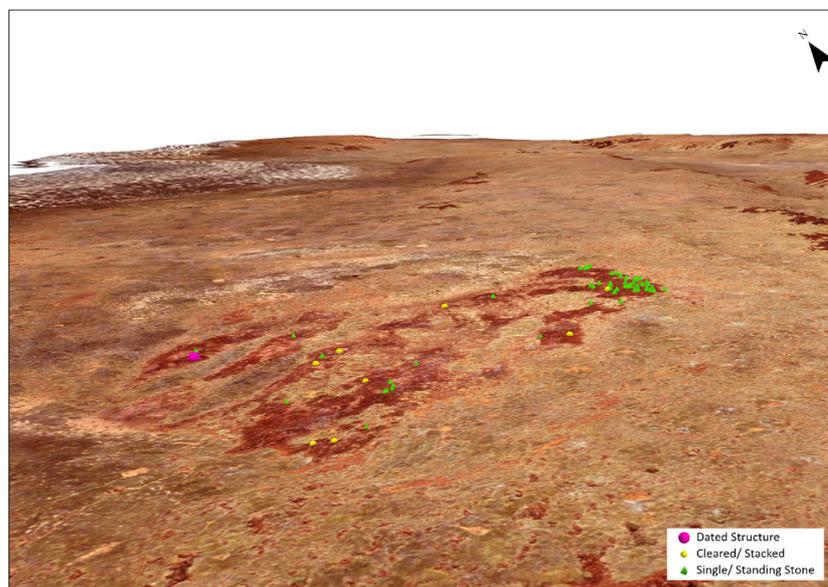

Figure 15: Visualisation of Rosemary 8 Site using the drone imagery showing locations of stone structures distributed across six platforms.
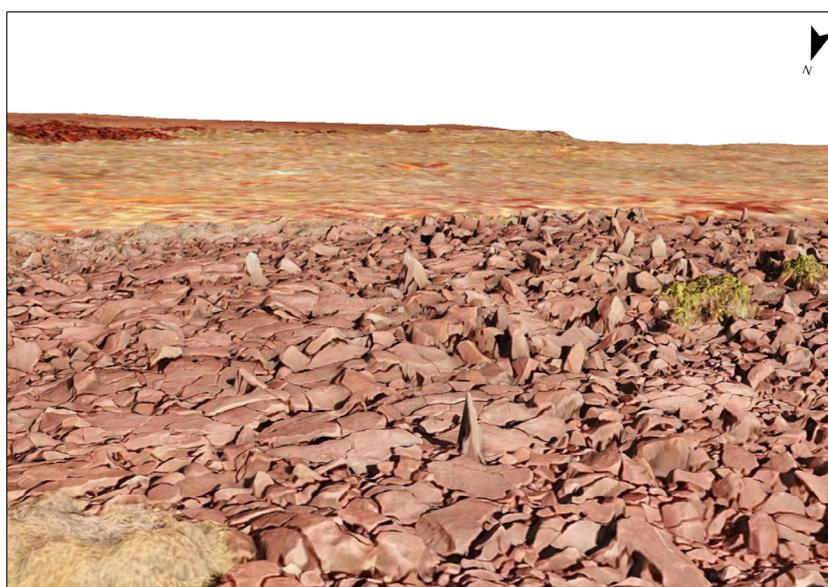

Figure 16: 3D Model (mesh) of the central portion of Platform 6 at Rosemary 8.

Nine (14%) of the stone structures at Rosemary 8 are circular stacked/cleared structures. One with a midden deposit in it (**Figure 10D**) has been dated to between 8063–7355 cal years BP and been interpreted as part of a series of grouped domestic structures (McDonald and Berry 2016).

We used photogrammetric imagery of this dated circular structure on Rosemary 8 to assess if it would be feasible for the DHSC project to locate similar circular structures in the underwater bathymetric LiDAR dataset, to supplement the landscape approach and to begin directly identifying targets for future diving work (Wiseman et al. 2020). Unlike the finding made in respect to standing stones (above), there are enough LiDAR data points to characterise and measure these features (**Figure 18**). However, when viewed at a landscape scale there is still little in the elevation profiles compared to the natural variability in the stones and spinifex features thus the footprint of these structures is subtle.

The elevation data combined with the ground-level photogrammetry provided control points for geo-referencing and preventing distortion. The section through the feature was generated by the LiDAR pointcloud in GlobalMapper17, which proved useful for measuring the house structure, but less useful for locating such a feature in the landscape.

Comparison of LiDAR and RPA data: finding features in the landscape

We also undertook a comparison of the RPA and LiDAR outputs to compare the accuracy and resolution of the datasets when it came to stacked features in rocky background contexts (see **Figure 7**). We have determined that the LiDAR data is more accurate in terms of generating a digital elevation model and its absolute position/elevation, but the RPA data provides models with significantly higher resolution, albeit with a loss of positioning in the

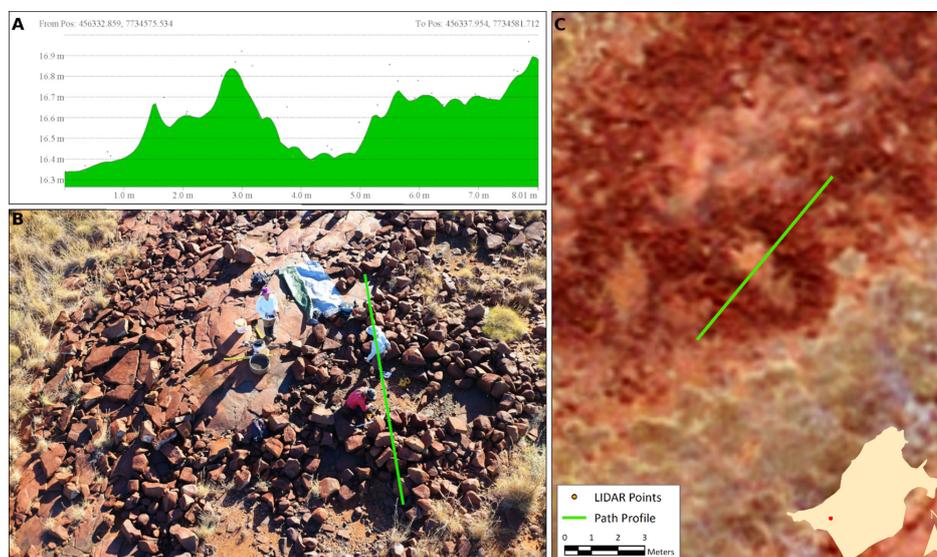**Figure 17:** 3D Model of standing stone at Rosemary 8 (images and model courtesy of Carla Schroer).

Figure 18: A) Section SE to NE through stone feature **B)** Stone feature during excavation (drone photograph) **C)** Location of section through the feature measuring height data generated by the LiDAR.

landscape. This difference in resolution sometimes precluded direct geospatial comparisons between images that could not be precisely aligned against each other.

Our lower density LiDAR point clouds resulted from the higher altitude flight lines (necessitated by the bathymetric LiDAR safety requirements). A flight pattern flown specifically to produce high-resolution terrestrial data could achieve 7–8 cm spacing with the current equipment. We recommend that this would allow for better visualisation of some of the structures; however, it is still unlikely that standing stones could be effectively identified at this resolution.

Rosemary Island Area 2 provides a good comparative dataset to explore the differences between the available RPA and LiDAR data because here we have the highest resolution LiDAR on the island as well as some good examples of cleared/stacked structures that were captured by RPA (see **Figure 2**). RIA2-2017-DF010 (**Figures 10A** and **19**) shows a fairly ephemeral cleared structure. RIA2-2017-DF012 (**Figures 10B** and **20**) shows a clearly stacked circular structure. Both types were examined to demonstrate these differences; structures are located in relatively clear, level areas away from spinifex and provide
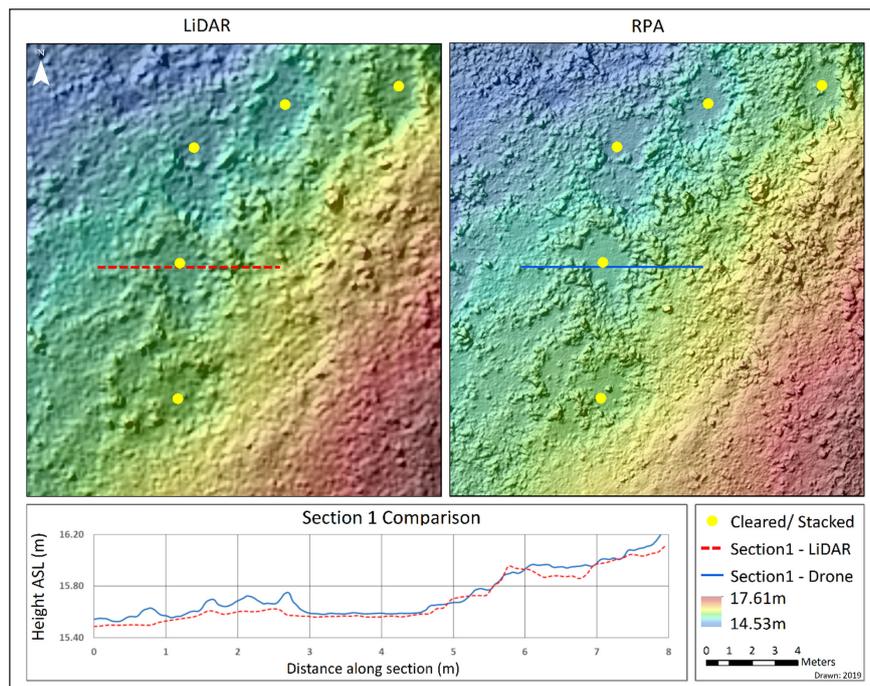
Figure 19: Feature RIA2-2017-DF010 at Northern Beach Platform. Comparison of LiDAR vs. RPA.
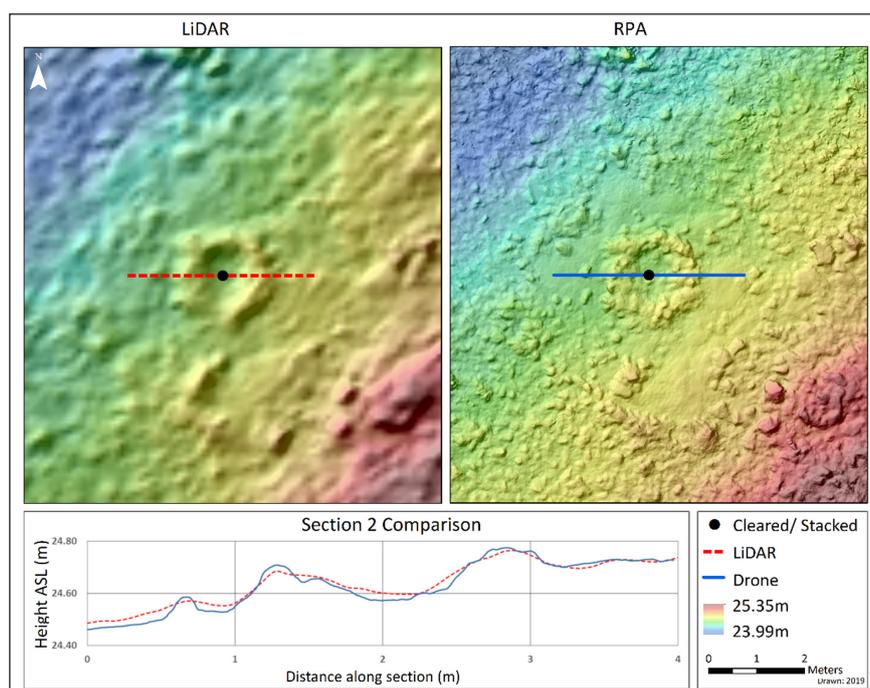
Figure 20: Feature RIA2-2017-DF012 in Sample Area 2. Comparison of LiDAR vs. RPA.

'best case' conditions for identification in the imagery (see **Figures 19** and **20**). Sections generated from both LiDAR and drone DEM/DSM models and were created in ArcGIS.

Both **Figures 19** and **20** show that the RPA ortho imagery and DSM provide significantly higher resolution for identification of these structures. The profile graphs also clearly show the stacked edges of these structures with the more level areas in the centre of these structures. At the centre of DF010 provides 2 m of level ground, enough for a person to sit – or even lie – comfortably.

The downside of the RPA imagery relates to global accuracy. During fieldwork we did not use surveyed Ground Control Points (GCP), resulting in an overall shift between the RPA and LiDAR imagery. This is relatively easily rectified by georeferencing the RPA data to the LiDAR (e.g. at DF010 the difference is by 3 m to a direction of 287º on the x/y axis). There is a similar shift required to the z axis as the RPA records z values as height above takeoff. Unfortunately the z axis also has radial distortion errors which seems to increase over sloping ground and towards the edges of the drone flight. This is a known problem for which the solutions involves changes to collection techniques, though ultimately the problem will persist, just to a lesser extent (James and Robson 2014). Elevation values collected by RPA should therefore be used mindfully, so that such errors can be accounted for during analysis.

Discussion
Analysis of LIDAR results and known features
In this paper we have shown the opportunities and constraints related to the digital reconstruction of landscapes to model multiple types of hunter-gatherer stone structures. The relatively unobtrusive nature of these anthropogenic constructions means that while LiDAR and RPA imagery can be used to map, reconstruct and visualise known stone structures, it is not possible at this stage to automate the detection of stone features using these techniques at a landscape scale. For example, Lidar point clouds are not able to distinguish between circular stone arrangements and some circular spinifex growth forms which have similar size, relief and shape. Nor were point clouds able to distinguish smaller standing stones which, if captured, appear as a single point floating above the ground surface. Given these uncertainties it was determined that the post processing of point cloud data requires knowledge about the location of the stone structures so that visualisation parameters may be altered to minimise the point clouds covering these features being classified as 'background noise'. We have also determined that aggressive filtering, necessary to remove the 'noise' created by vegetation (particularly spinifex) may result in circular stone features also being completely filtered out. Notwithstanding, the utility of topographic LiDAR in the accurate site positioning (once features are identified by terrestrial survey) within the broader landscape context: or visualising the cultural features within the environment. Larger landscape features and patterning (like agricultural fields, extensive stone fishtraps and ceremonial and monumental structures) are the most suitable scale for LiDAR

detection. The RPA imagery and imagery derived DSM, was found to be quite affective at capturing site features documented during pedestrian survey, but also mapping the local (hectare scale) landscape context in which these known features and sites are integrated.

The use of remote sensing technology to locate or identify sites in unknown landscapes was most effective when combining multiple collection and visualisation technologies. That is higher altitude Airborne topographic LiDAR and aerial photos which capture environments at the landscape scale, combined with lower altitude aerial RPA technologies, and generating photogrammetrically derived RPA DSMs, and high-res RGB-imagery that capture cultural features and landforms at the site scale. This multi-scalar approach has the potential (at the right level of detail) to fulfil our quest to use these remote technologies to assist us in prospecting and predictively locating terrestrial sites, particularly in areas were vegetation limits pedestrian surveys or obscures ground features.

While the idea of machine learning and ultimately auto-detection of archaeological sites at a landscape scale is a promising panacea, this is not yet a viable option for Australian hunter-gatherer archaeological survey work in the Pilbara. The approaches outlined in this study have shown that the combination of landscape scale LiDAR surveys, site scale RPA surveys, and pedestrian surveys and systematic recording provides an opportunity for archaeologists, Aboriginal stakeholders and where appropriate the wider community, to immerse themselves virtually into the cultural environment. The techniques employed here are ideal for the detailed documentation of archaeological material. They also provide the opportunity to visualise and interpret how and why a particular landscape might have been occupied in the past. With this knowledge, comes the ability to develop more highly-resolved predictive models, which also allow for the targeted prospection of cultural heritage though the emerging field of underwater landscape archaeology (e.g., O'Leary et al., 2020 and Benjamin et al., 2020).

Here we provide some general guidance for site detection and visualisation using remote sensing technologies in the Pilbara:

· A pedestrian survey is still the most effective method to identify and/or ground-truth the presence of hunter-gatherer stone structures in the Pilbara;
· The firing of Spinifex has variable effects on the vegetation depending on the intensity of the fire and occurrence of strong winds, either partially or completely exposing the underlying ground surface with the latter conditions providing an advantageous window for both pedestrian and remote surveys;
· It is difficult to post process or "machine-learn" the removal of spinifex from a DEM, partly because its density (i.e., the laser beam is unable to penetrate through the vegetation and contact the ground surface) and partly because it replicates the rocky structures it is often concealing;
· There is a trade-off between the area covered by LiDAR survey and the density of point clouds. For exam-

ple, the resolution of the LiDAR point cloud collected for this project is too sparse to define clearly the location of standing stones from the background scatter. Rather, it is better suited to locating stone structures that involve multiple stones that have either been removed or stacked to create these features;

- RPA imagery is better than LiDAR for prospecting stone features, however it helps to know structures are present (i.e. aerial photography should accompany pedestrian survey augmented by the collection of accurate GPS co-ordinates). Accurate ground location data utilised during point-cloud processing will ensure appropriate filtering of 'noise'. To collect RPA imagery for all potential stone circle areas over an area the size of Rosemary Island would be quite a challenge;

- The main value of LiDAR – as available from these non-optimised flights – is the accurate defining and visualising of landscapes and locations, which can then be used to measure some of the larger (>1 m) stone features in the landscape;

- Visualisation (using photogrammetry to produce data collected by LiDAR, RPA, conventional DLSR and microscopic images) provides multiscale datasets to communicate archeologically significant findings.

Conclusion

A range of remote sensing hardware and software technologies are being used to successfully locate and characterise agricultural and monumental archaeological sites at a landscape scale through dense vegetation (e.g. Bedford et al. 2018; Canuto et al. 2018). We have shown that developing these innovative methodologies with Australian hunter-gatherer sites is still challenging, and conclude that there is no easy replacement for pedestrian survey and detailed recording exercises to document cultural sites in the Pilbara, and specifically Murujuga, landscapes. We advocate that the best-practice approach for utilising airborne remote sensing of archaeological heritage is at multiple spatial scales, particularly in the rocky Pilbara environs, where spinifex vegetation is common. While LiDAR is not yet a useful remote-sensing tool for discovery of hunter-gatherer standing stones, and has only limited success with stacked stone features in this Pilbara landscape, we have demonstrated here its utility, in combination with other scales of photogrammetry, the techniques for accurately mapping and visualising these significant cultural heritage items.

Limiting factors relate to the typically large areas which archaeologists attempt to cover during their research and management programs – these also reflecting the human scale of the highly mobile arid-zone peoples and their cultural landscapes that are being investigated. This arid landscape study has also identified the extent of unmanaged (by burning) spinifex vegetation, which masks the ground surface, impeding all forms of pedestrian, vehicle or airborne survey. And the final limiting factor, as always with Big Data, is the trade-off between survey resolution and data file sizes, and the corresponding computing time required to process the resulting datasets.

References

Bedford, S, Siméoni, P and **Lebot, V.** 2018. The anthropogenic transformation of an island landscape: Evidence for agricultural development revealed by LiDAR on the island of Efate, Central Vanuatu, South-West Pacific. *Archaeology in Oceania,* 53(1): 1–14. DOI: https://doi.org/10.1002/arco.5137

Benjamin, J, McCarthy, J, Wiseman, C, Bevin, S, Kowlessar, J, Astrup, PM, Naumann, J and **Hacker, J.** 2019. Integrating Aerial and Underwater Data for Archaeology: Digital Maritime Landscapes in 3D. In: McCarthy, JK, Benjamin, J, Winton, T and van Duivenvoorde, W (eds.), *3D Recording and Interpretation for Maritime Archaeology*. Cham: Springer International Publishing. DOI: https://doi.org/10.1007/978-3-030-03635-5_5

Benjamin, J, O'Leary, M, McDonald, J, Wiseman, C, McCarthy, J, Beckett, E, Morrison, P, Stankiewicz, F, Leach, J, Hacker, J, et al. 2020. Aboriginal artefacts on the continental shelf reveal ancient drowned cultural landscapes in northwest Australia. *PLOS ONE*. DOI: https://doi.org/10.1371/journal.pone.0233912

Bird, DW, Bird, RB and **Parker, CH.** 2005. Aboriginal Burning Regimes and Hunting Strategies in Australia's Western Desert. *Human Ecology*, 33(4): 443–464. DOI: https://doi.org/10.1007/s10745-005-5155-0

Blender Online Community. 2019. *Blender – a 3D modelling and rendering package 2.8 Beta*. Amsterdam: Stichting Blender Foundation. Online access at: http://www.blender.org.

Burrows, ND, Liddelow, GL and **Ward, B.** 2014. A Guide to Estimating Fire Rate of Spread in Spinifex Grasslands (Mk2). Perth: Department of Parks and Wildlife.

Canuto, MA, Estrada-Belli, F, Garrison, TG, Houston, SD, Acuña, MJ, Kováč, M, Marken, D, Nondédéo, P, Auld-Thomas, L, Castanet, C, et al. 2018. Ancient lowland Maya complexity as revealed by airborne laser scanning of northern Guatemala. *Science*, 361(6409): 1–17. DOI: https://doi.org/10.1126/science.aau0137

Crabtree, SA, Bird, DW and **Bird, RB.** 2019. Subsistence Transitions and the Simplification of Ecological Networks in the Western Desert of Australia. *Human Ecology*, 47(2): 165–177. DOI: https://doi.org/10.1007/s10745-019-0053-z

Dortch, J, Balme, J, McDonald, J, Morse, K, O'Connor, S and **Veth, P.** 2019a. Settling the West: 50 000 years in a changing land. *Journal of the Royal Society of Western Australia*, 102: 30–44.

Dortch, J, Beckett, E, Paterson, A and **McDonald, J.** 2019b. Stone artifacts in the intertidal zone, Dampier Archipelago: Evidence for a submerged coastal site in Northwest Australia. *The Journal of Island and Coastal Archaeology*, 1–15. DOI: https://doi.org/10.1080/15564894.2019.1666941

Dyer, MP. 2018. Scrimshaw. Encyclopaedia of Marine Mammals (Third Edition). In: Würsig, B, Thewissen, JGM and Kovacs, KM (eds.), Academic Press: 841–845. DOI: https://doi.org/10.1016/B978-0-12-804327-1.00017-0

Emmitt, JJ, Allely, K, Davies, B, Hoffman, E and **Holdaway, SJ.** 2020. Preliminary archaeological survey of shell mounds at Kwokkunum, Albatross Bay, Cape York, Australia. *Queensland Archaeological Research*, 23: 9–24. DOI: https://doi.org/10.25120/qar.23.2020.3718

ESRI. 2020. *ESRI World Imagery Dataset*, Contributions from: Esri, D., GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Evans, D. 2016. Airborne laser scanning as a method for exploring long-term socio-ecological dynamics in Cambodia. *Journal of Archaeological Science*, 74: 164–175. DOI: https://doi.org/10.1016/j.jas.2016.05.009

Gallant, JC, Dowling, TI, Read, AM, Wilson, N, Tickle, P and **Inskeep, C.** 2011. SRTM-derived 1 Second Digital Elevation Models Version 1.0. Canberra: Geoscience Australia, Department of Industry, Tourism and Resources.

Geoscience Australia. 2004. *Geodata Coast 100K 2004 Dataset*.

Harman, J. 2011. Using DStretch to investigate paintings in Cueva San Borjitas, BCS Mexico. *Society for Americal Archaeology 76*. Sacramento, California.

Harman, J. nd. *Image Enhancement using DStretch* [Online]. Available at: http://www.dstretch.com/DStretchHandout.pdf [last accessed 18/3/2020].

James, MR and **Robson, S.** 2014. Mitigating systematic error in topographic models derived fromUAVand ground-based image networks. *Earth Surface Processes and Landforms*, 39: 1413–1420. DOI: https://doi.org/10.1002/esp.3609

Kreij, A, Scriffignano, J, Rosendahl, D, Nagel, T and **Ulma, S.** 2018. Aboriginal stone-walled intertidal fishtrap morphology, function and chronology investigated with high-resolution close-range Unmanned Aerial Vehicle photogrammetry. *Journal of Archaeological Science*, 96: 148–161. DOI: https://doi.org/10.1016/j.jas.2018.05.012

McDonald, J. 2015. I must go down to the seas again: Or, what happens when the sea comes to you? Murujuga rock art as an environmental indicator for Australia's north-west. *Quaternary International*, 385(22): 124–135. DOI: https://doi.org/10.1016/j.quaint.2014.10.056

McDonald, J and **Berry, M.** 2016. Murujuga, Northwestern Australia: When Arid Hunter-Gatherers Became Coastal Foragers. *The Journal of Island and Coastal Archaeology*, 12(1): 24–43. DOI: https://doi.org/10.1080/15564894.2015.1125971

McDonald, J, Mulvaney, K, Paterson, A, Veth, P, Dortch, J, Beckett, E, Reynen, W, Blunt, Z, Berry, M, Burcham, A and **De Koning, S.** in prep. 2020. The rock art, stone features and open site and historic excavations of the Murjuga: Dynamics of the Dreaming Project 2014–2018. CRAR+M Monograph No. 2, UWA.

McDonald, J, Paterson, A and **Anderson, R.** 2019. Rock art shows early contact with US whalers on Australia's remote northwest coast. *The Conversation*, 19 February [online access at https://theconversation.com/rock-art-shows-early-contact-with-us-whalers-on-australias-remote-northwest-coast-104931] last accessed 18 July 2020

McDonald, J, Reynen, W, Ditchfield, K, Dortch, J, Leopold, M, Stephenson, B, Whitley, T, Ward, I and **Veth, P.** 2018. Murujuga Rockshelter: First evidence for Pleistocene occupation on the Burrup Peninsula. *Quaternary Science Reviews*, 193: 266–287. DOI: https://doi.org/10.1016/j.quascirev.2018.06.002

Morris, K. 1990. *Dampier Archipleago Nature Reserves: Management Plan*, Published by Department of Conservation and Land Management. https://www.dpaw.wa.gov.au/images/documents/parks/management-plans/decarchive/dampier_archipelago.pdf (accessed July 2020).

Morrison, P and **McDonald, J.** 2019. Visualising Aboriginal Cultural features on Rosemary Island, Dampier Archipleago. A project involving photogrammetric reconstructrion of Aboriginal and historic engravings. Poster and video (by Patrick Morrison, narrated by Jo McDonald) to Pawsey Summer Intern programme. https://youtu.be/ANtpNDfmeXo.

O'Leary, MJ, Paumard, V and **Ward, I.** 2020. Exploring Sea Country through high-resolution 3D seismic imaging of Australia's NW shelf: Resolving early coastal landscapes and preservation of underwater cultural heritage. *Quat. Sci. Rev.*, 239: 106353. DOI: https://doi.org/10.1016/j.quascirev.2020.106353

Paterson, A, Anderson, R, Mulvaney, K, de Koning, S, Dortch, J and **McDonald, J.** 2019. So ends this day: American whalers in Yaburara country, Dampier Archipelago. *Antiquity*, 93(367): 218–235. DOI: https://doi.org/10.15184/aqy.2018.186

Veth, P, Ditchfield, K and **Hook, F.** 2014. Maritime deserts of the Australian northwest. *Australian Archaeology*, 79(1): 156–166. DOI: https://doi.org/10.1080/03122417.2014.11682032

Veth, P, McDonald, J, Ward, I, O'Leary, M, Beckett, E, Benjamin, J, Ulm, S, Hacker, J, Ross, PJ and **Bailey, G.** 2019. A Strategy for Assessing Continuity in Terrestrial and Maritime Landscapes from Murujuga (Dampier Archipelago), North West Shelf, Australia. *The Journal of Island and Coastal Archaeology*, 1–27. DOI: https://doi.org/10.1080/15564894.2019.1572677

Walsh, FJ, Sparrow, AD, Kendrick, P and **Schofield, J.** 2016. Fairy circles or ghosts of termitaria? Pavement termites as alternative causes of circular patterns in vegetation of desert Australia. *Proceedings of the National Academy of Sciences*, 113(37): E5365. DOI: https://doi.org/10.1073/pnas.1607860113

Wiseman, C, O'Leary, M, Hacker, J, Stankiewicz, F, McCarthy, J, Beckett, E, Leach, J, Baggaley, P, Ulm, S, McDonald, J, et al. in prep. A multi-scalar approach to marine survey and underwater archaeological site prospection in Murujuga, Western Australia. *Paper submitted to Quaternary International; review comments processed in July 2020.*