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O'Leary, Michael, Benjamin, Jonathan, McDonald, Jo et al. (2 more authors) (2026) Stone artefacts on submerged land surfaces:a response to Larcombe et al. Geomorphology. 110053. pp. 1-6. ISSN: 0169-555X

https://doi.org/10.1016/j.geomorph.2025.110053

Stone artefacts on submerged land surfaces: A response to Larcombe et al

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Abstract

Larcombe et al. (2025) challenge the work of the Deep History of Sea Country team regarding the provenance and mobility of lithic artifacts on the seafloor of Murujuga, Northwestern Australia. They propose that these artefacts were originally deposited on terrestrial Holocene landforms, and subsequently transported into the marine environment, challenging our interpretation of primary deposition on pre-inundation land surfaces.

The authors largely base their conclusions on a hydrodynamic model and a 32-year satellite-derived shoreline dataset. Here we highlight the critical shortcomings in their approach including the application of a low resolution and poorly validated regional hydrodynamic model to infer current speeds at the local site level and by extension the transport of lithic artefacts at the seabed, and the analysis and interpretation of satellite derived shorelines which, when scrutinised, were found to be unrepresentative of real-world conditions.

By emphasizing the importance of rigorous field validation and contextual site analyses, we reaffirm the preservation and integrity of Murujuga's underwater cultural heritage, while challenging the scientific rigor of the conclusions presented by Larcombe et al.

1.0 Introduction

Larcombe et al. argue that lithic artifacts found on the seabed at Murujuga must have been extensively reworked by currents and other natural processes, thereby invalidating the hypothesis that these artifacts represent primary discard on a pre-inundation land surface. They further assert that, since the artifacts cannot be directly dated, they could have originated from deposits of any age, including recent erosion from adjacent land surfaces and movement by tidal currents or wave action. These arguments, however, are not new, they form part of a longer-running debate including Ward et al. (2022 retracted) and our formal response (Benjamin et al., 2022). Our site investigations, detailed in previous publications (Dortch et al., 2019; Benjamin et al., 2020, 2023a, 2023b; Wiseman et al., 2021; O'Leary et al., 2023), employed field and laboratory observations, experimental studies, and empirical measurements, which contradict, both on theoretical and observational grounds, the hypothesis of large-scale erosion and artifact displacement from adjacent land surfaces.

Their argument is based on an a priori assumption that tidal currents and cyclonic activity must have caused significant artifact displacement. Their study focuses on reinforcing this belief through theoretical models, hypothetical scenarios, analogies drawn from unrelated contexts, and use of questionable datasets and concepts, rather than engaging with the field-based evidence we have presented.

Their critique relies on low-resolution hydrodynamic modelling and coastline change mapping that have not been validated against local field observations near the sites in question. As demonstrated below, (1) their hydrodynamic model is incapable of capturing the complex bathymetric terrain of Cape Bruguieres Channel and Flying Foam Passage in Murujuga, and hydrodynamic processes that characterize them, and (2) their modelled shorelines are not supported by real-world evidence. Theoretical models, no matter how sophisticated, cannot replace field-based observations.

The central issues, in our view, are twofold:

1. Were the underwater and intertidal artifacts at Cape Bruguieres Channel and Flying Foam Passage originally discarded on a pre-inundation land surface, or were they transported by natural processes from more recent (mid-Holocene or later) sites on the post-inundation terrestrial land surface? By "pre-inundation land surface", we refer to surfaces exposed and utilized during periods of lower sea level and subsequently submerged by Terminal Pleistocene/Early Holocene postglacial sea-level rise.

2. Can such pre-inundation materials survive the impacts of sea-level rise, including erosion by wave action, tidal currents, and cyclonic activity? While Larcombe et al. dismiss this possibility a priori, growing evidence from field studies globally highlights the role of locally protective conditions in facilitating underwater cultural site preservation (e.g., Flemming et al. 2017)

In the following sections, we critically examine the modelling approaches employed by Larcombe et al. (2025). Close inspection reveals a lack of model validation, resulting in outputs that do not reflect local field observations. This approach, coupled with a disregard for higher-resolution site-specific data, raises concerns about the integrity of their interpretations and undermines the validity of their claims.

2.0 Hydrodynamic Modelling: applying low-resolution models to infer site level conditions

2.1 Hydrodynamic modelling and model validation

Larcombe et al. rely on a regional scale hydrodynamic model with a 500 m grid cell and 10 m vertical thickness created from a 200 m resolution bathymetric grid to infer current speeds and directions at the local site level. While a model with this resolution performs well in open marine settings, we question its reliability in areas with highly variable bathymetric terrain, complex coastal geography, narrow channels, and broad areas of shallow fringing reefs. For example, the modelled grid used by Larcombe et al. clearly shows that a significant portion of each cell overlies both shallow fringing reef and deeper channel (**Figure 1**). Not only are the depths radically different between these two bathymetric features but so too is the bed roughness. This complexity becomes homogenised within each modelled grid cell. By simple virtue of the coarseness of the grid, the model is unlikely to reproduce actual current velocities for a given location and therefore leads to questionable calculations of sediment transport rates.

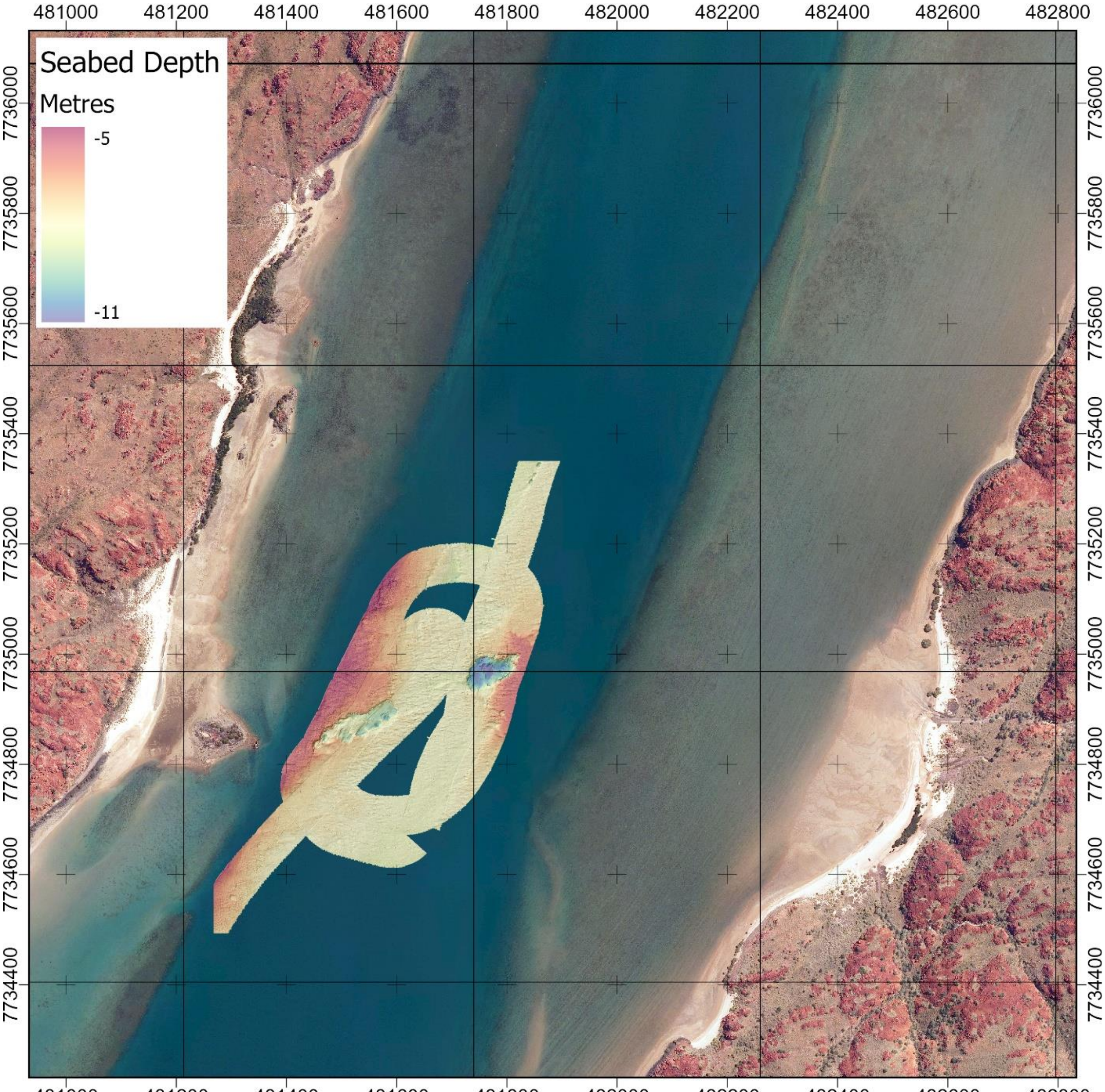


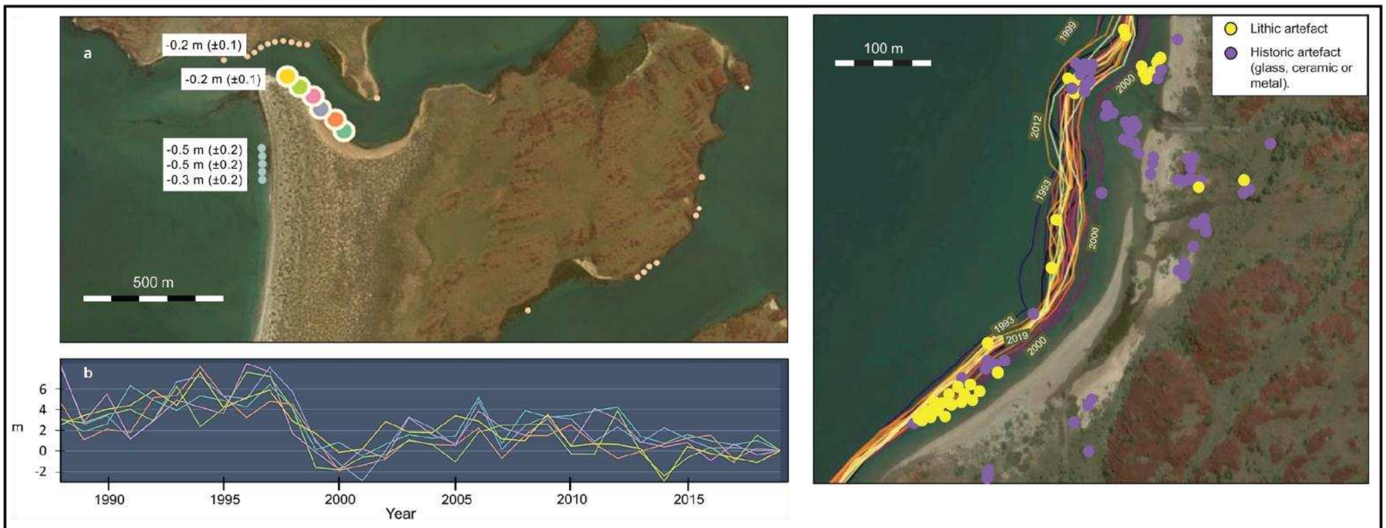
Figure 1. Aerial photo (24/08/2012) of Flying Foam Passage showing island shorelines, shallow fringing reefs and deeper channel. Also shown is the track of the multibeam echosounder used to measure the bathymetry in the channel. The colour coding of depth shown in the legend refers to the areas covered by this multibeam track. This shows the location of a seabed depression, interpreted as a former freshwater spring, and where artefacts have been found. Black lines represent an exact overlay of the 500 m grid cells used in the Larcombe et al. (2025) hydrodynamic model. Note the highly variable bathymetry contained within each of the grid cells that covers the multibeam track, and the equally variable range of geomorphological conditions shown in the other grid cells,

Larcombe et al. validate their model by stating that its results for current speeds in Flying Foam Passage closely align with measurements reported in Forde (1985) and Pearce et al. (2003). However, Forde's report contains only a brief reference to current speeds in Flying Foam Passage, stating: "*The few current measurements that have been made in this channel suggest that peak spring tidal flows exceed 2 m/s*." Crucially, Forde does not report actual current speed measurements, nor specify the time, location, duration, or depth of these measurements; he only provides a suggestion of peak current speeds. Pearce et al. did not produce original hydrographic measurements from Flying Foam Passage but instead cite the Forde report. Despite Benjamin et al.'s. (2023a) publication of 5 months of in situ current measurements in Flying Foam Passage, Larcombe et al. dismiss the validity of this real-world data in favour of a model that has not been rigorously calibrated against real-world conditions. They appear to be suggesting that our directly measured current flows cannot be relied upon as they do not conform to the predictions of their own model. This a priori approach prioritises unvalidated hydrodynamic modelling and adjustments over direct observational data. By relying on an a priori approach Larcombe et al. introduce confirmation bias, where results are interpreted to best fit their model, even when empirical data suggest otherwise.

3.0 Reassessing Coastal Erosion and Artefact Context: Limitations of Satellite-Derived Shoreline Data in Murujuga

3.1 Shoreline analysis using satellite-derived annual coastal position data

Larcombe et al. use Geoscience Australia's satellite-derived annual coastal position data (1988–2019), which is a "wetted-line" proxy to challenge claims of long-term stability in coastal sedimentary deposits and submerged artifacts in Murujuga. Analysing this dataset (see Figures 12 and 13 in Larcombe et al., (2025), reproduced in **Figure 2** below), Larcombe et al. infer annual erosion rates of approximately 0.1 m/year along the Cape Bruguières Channel since 1988 and a significant coastal retreat of up to 12 m in the late 1990s. Similarly, at the intertidal site on Dolphin Island (the eastern shoreline of Flying Foam Passage) reported by Dortch et al. (2019), they infer 30 m of shoreline retreat over the 32-year period. Based on this analysis, Larcombe et al. question the primary context of lithic artefacts found in the intertidal and subtidal zones at Dolphin Island and Cape Bruguieres Channel and instead suggest that the artifacts have been displaced into the water and transported offshore onto the seabed from archaeological sites on adjacent land surfaces as the coastline eroded.



Larcombe et al., Figure 12 [page 13] Larcombe et al., Figure 13 [page 13]

Figure 2. Here we present Figures 12 and 13 published in Larcombe et al., 2025. These figures claim to show positions of annual shorelines between 1988 and 2019

The satellite-derived annual coastal position data used by Larcombe et al. was developed by Bishop-Taylor et al. (2021) and can be viewed at https://maps.dea.ga.gov.au/story/DEACoastlines. The method uses 30 m resolution Landsat imagery to calculate the Modified Normalized Difference Water Index (MNDWI), which distinguishes between land and water, and then applies tidal corrections using global tide models and filters to generate polylines representing the dominant shoreline position at Mean Sea Level for each year. Under optimal conditions, this method can track long-term coastal changes, achieving sub-pixel precision. However, Bishop-Taylor et al. (2021) note that the method's accuracy is limited in low-gradient coastal environments, such as tidal flats, where small vertical changes in sea level can cause substantial horizontal shifts in shoreline position, complicating precise mapping. Along rocky coasts, they note root mean square errors of 16.7 m. These errors create challenges when working at finer scales.

3.2 Discrepancies and misinterpretation of Satellite-Derived Shoreline Data on Dolphin Island

With the above limitations in mind, we draw attention to a discrepancy in Larcombe et al.'s (2025) Figure 13, which overlays 32 annual shoreline polylines on an aerial photograph (**Figure 2**). Although the year of the aerial photograph is not provided, it is presumed to fall between 1988 and 2019. We would expect the polyline that corresponds to the year of the image to align at least approximately with the observed waterline (tide depending), yet none of the polylines closely aligns with the beach-water interface depicted in the photograph. To investigate further, we validated satellite-derived shoreline positions using georectified aerial photographs from 2023, 2019, and 2012, as well as LiDAR imagery from 2018 (**Figure 3**). The 2023 and 2012 aerial photos were purchased from Landgate (WA State Government mapping agency) with a ground measurement of 0.15 m and 0.5 m, and stated accuracy of ±1 m and ±5 m, respectively. The 2019 orthomosaic image was realigned against the 2023 image in ArcGIS Pro using the georectification tool. Black and white historical aerial photos were georeferenced in ArcGIS Pro using the georectification tool applying a second order polynomial transformation with calculated position errors of less than 2 m.

The beach can be identified in each image (**Figure 3**) as the area of lighter coloured sand, and the darker coloured sand seaward of the beach as the tidal flat. We used the updated 1988 to 2023 DEA shoreline dataset to plot all 36 shoreline polylines over the aerial photographs and LiDAR image, with the corresponding year's polyline coloured black. Note that in our aerial photo analysis of shoreline position we have used the toe of the beach as it provides the best contrast between beach and tidal flat; it also represents the seaward-most extent of the beach zone, and is positioned further seaward than the beach waterline. This analysis reveals that none of the 2023, 2019, 2018, or 2012 shorelines (black polylines) match the observed toe-of-beach position in the corresponding aerial photograph and LiDAR image, with misalignments of up to 80 m. These discrepancies are easily explained by the presence of a broad tidal flat seaward of the beach (**Figure 3**). As Bishop-Taylor et al. (2021) acknowledge, such environments can severely compromise the accuracy of shoreline mapping methods, the result here being that all 36 modelled shorelines are situated over the tidal flat and therefore do not represent the beach/shoreline position.

These findings unequivocally demonstrate that the satellite-derived shorelines employed by Larcombe et al. to critique Dortch et al. (2019) are fundamentally flawed and fail to match the corresponding beach positions. As a result, Larcombe et al.'s extensive interpretations and criticisms (asserting that this intertidal archaeological site is secondary in nature due to erosion from the land) are effectively based on a timeseries of "phantom shorelines" that lack any substantive grounding in reality.

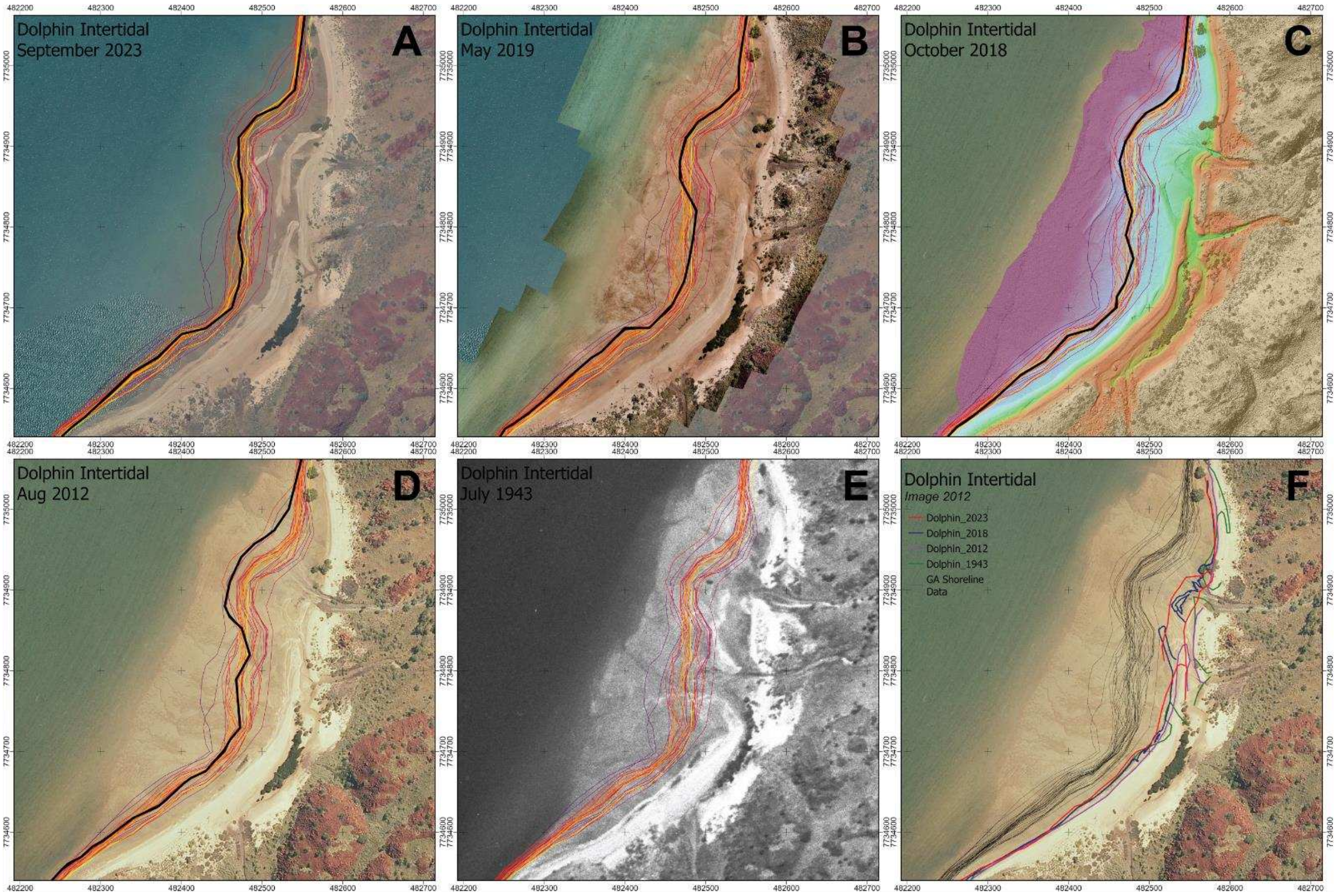


Figure 3. Panels A to E show aerial photographs of the Dolphin Island intertidal site with the Satellite Derived Shoreline (SDS) polylines overlayed, the colour scale represents the temporal range [1988 Most recent]. The black line in panels A to D is the satellite-derived-shoreline (SDS) polyline that corresponds with the year of the aerial photograph. Note that none of the corresponding SDS polylines align with the corresponding beach/shoreline. Panel E show SDS polylines over an air photograph from 1943. Coloured lines in Panel F show the shoreline position for each of the aerial photograph/LiDAR DEM images using the 2012 air photograph as the base image, with all SDS polylines shown in black.

3.3 Discrepancies and misinterpretation of Satellite-Derived Shoreline Data in Cape Bruguieres Channel

We extend this critique to a similar analysis at the Cape Bruguieres Channel shoreline using the same dataset. Curiously, Larcombe et al. choose not to present the shoreline polylines in their Figure 12 (see **Figure 2**) but instead display dots indicating rates of shoreline change. Again, we carried out an independent test by plotting the satellite-derived polylines against a drone orthophoto of the Cape Bruguieres Channel from 2019.

Our analysis reveals that all Larcombe et al.'s satellite-derived polylines used to challenge the findings of Benjamin et al. (2020) are situated in the Cape Bruguieres Channel, notably the 2019 polyline, which is offset from the 2019 shoreline by as much as 15 m (**Figure 4** right panel). This error in shoreline positions is clearly visible in the DEA-Coastlines online mapping toolbox https://maps.dea.ga.gov.au/story/DEACoastlines; this obvious error in shoreline position appears to have gone unnoticed by Larcombe et al.

Despite these large uncertainties and the fact that none of the satellite derived shorelines appear to align with the actual shoreline, Larcombe et al. use them to calculate a mean annual erosion rate of ~0.1 m/yr in the Cape Bruguieres channel since 1988, further stating: "*Whilst it might be tempting to extrapolate this measured rate over the last 33 years to longer periods and thus indicate many tens of metres of erosion, it would be unjustified, because there is no evidence for it."* (Larcombe et al. 2025, p. 9). This line of argument a reflects a significant oversight in reasoning.

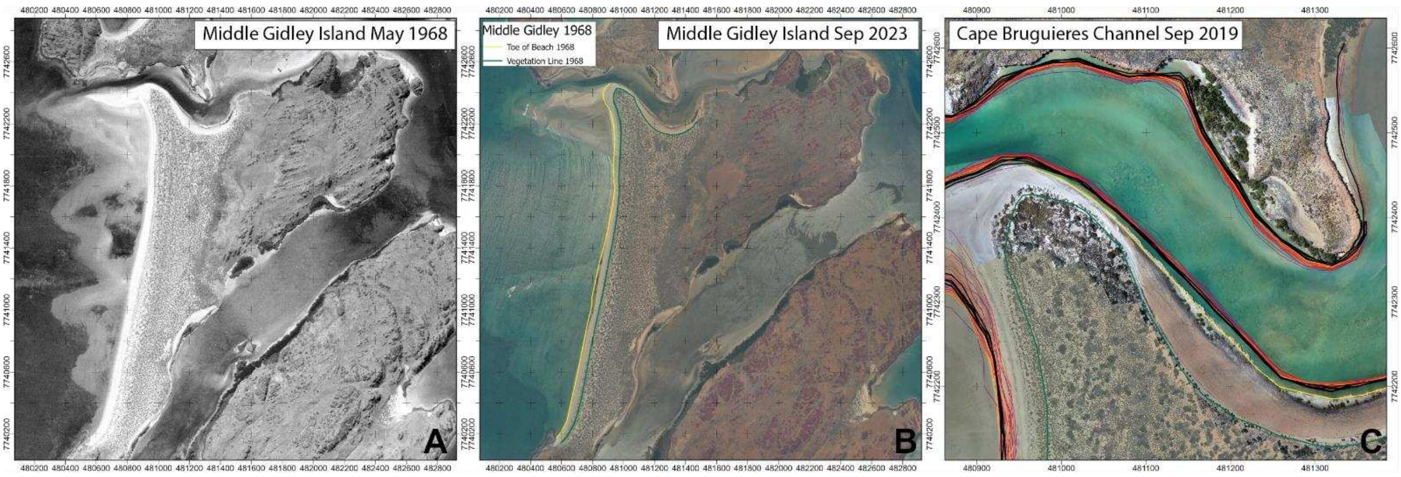


Figure 4. Panel A is an aerial Photograph of Middle Gidley Island from 1968 with Cape Bruguieres Channel shown top of Image. Panel B is an aerial photo of Middle Gidley Island from 2023, the yellow and green lines show the 1968 position of the toe of the beach and the vegetation line. Panel C is a high resolution orthomosaic image of Cape Bruguieres Channel from 2019 showing the 1968 position of the channel shoreline (yellow line) and vegetation line (green line), and the 32 Satellite Derived Shoreline (SDS) polylines, the colour scale represents the temporal range [1988 Most recent], the black line represents the 2019 SDS shoreline.

In fact, the record can be extended beyond the last 33 years, by comparing shoreline positions observed in a 2023 aerial photograph with a georeferenced aerial photograph from 1968 (**Figure 4**), a 55-year interval. When we overlaid the 1968 and 2023 images of Cape Bruguieres Channel to examine the position of the channel banks, the photographs showed minimal change, with an alignment offset of no more than 1–2 m, which is within the margin of georeferencing error. This new analysis suggests minimal erosion over the past five decades, and this is consistent with the heavily indurated limestone geology that forms the northern and southern banks of the Channel.

3.4 Coastal response to cyclones

Larcombe et al. also speculate about the role of cyclones in modifying coastal landscapes over multidecadal timescales, particularly their role in causing coastlines to erode and transport lithics off the land and into the water. To evaluate this claim, we conducted a detailed analysis comparing georeferenced 1943 aerial photographs of the Dolphin Island intertidal site to more recent imagery (**Figure 3** Panel F). Here we precisely determined the position of the toe of the beach for the years 2023 (red line), 2018 (blue line), 2012 (purple line) and 1943 (green line). When these shorelines are compared, they show almost no change in the position of the beach. A similar analysis on Middle Gidley Island's west facing beach, albeit over a shorter 55-year timespan, also shows stability and even shoreline accretion despite the impact of regular cyclone activity across this period (**Figure 4** Panel B and C). Contrary to Larcombe et al.'s speculations, our findings demonstrate that, despite the regular occurrence of (sometimes severe) cyclones over the past 50 to 80 years, the shoreline position at each of these sites has exhibited remarkable geomorphic stability.

4.0 Misuse of Definitions

Another type of argument used by Larcombe et al. is to set up a simple dichotomy between two opposing categories, defined in such a way as to exclude our observations from the category that corresponds to evidence of artefact deposition on a pre-inundation surface; and thereby claiming to refute our interpretation. Their discussion of 'in situ' remains is an apt example. Using a narrow text-book definition of 'in situ' – objects that have not moved or been disturbed since they were originally discarded – they argue that if artefacts have been moved after they have been discarded, they cannot be described as 'in situ'; and if they are not ‘in situ’ they cannot have been discarded on a pre-inundation land surface. Leaving aside questions of what evidence exists for post-depositional movement (none is provided), there is no logical connection between discard on a pre-inundation surface and post-depositional movement. Both can be true in some circumstances; artefacts could have been discarded on a pre-inundation surface and subsequently moved or disturbed, without necessarily implying erosion from an adjacent land surface. These are separate issues and should be assessed independently. Their argument about our use of the term ‘in situ’ merely serves to confuse these issues, oversimplifies what is in reality a complex chain of movements and modifications to lithic artefacts between the moment when they were first made to the moment when they were observed by an archaeologist in the field, and misrepresents how we previously used that term (see Benjamin et al. 2022, p. 814).

Another example is their claim that the Cape Bruguieres Channel artefacts are confined to the intertidal zone and have been ‘ponded’ by water currents, supposedly demonstrating that they are not ‘marine’. This is both irrelevant and factually incorrect. It is irrelevant because the issue is not whether artefacts are now in the intertidal or subtidal zone, in a non-marine or a marine context, but whether they were originally discarded on a pre-inundation land surface; incorrect because it is contradicted by our local field observations and measurements. These show that the Channel is never isolated from the open ocean and most artefacts are permanently under water.

5.0 Concluding Remarks

The reliance of Larcombe et al. on datasets with well-documented limitations, combined with a lack of rigorous validation and a disregard for empirical evidence, has resulted in conclusions that are fundamentally flawed. The use of satellite-derived shorelines, described by the dataset creators (Bishop-Taylor et al. 2021) as unsuitable for precise shoreline mapping in low gradient environments, exemplifies this issue. Despite these acknowledged limitations, Larcombe et al. have leveraged this dataset to construct an unfounded critique of Dortch et al.’s (2019) and Benjamin et al.’s (2020) findings, culminating in a narrative underpinned by "phantom shorelines". Similarly, their use of over-simplified definitions to exclude data that contradict their own opinions shows an unwarranted preference for a priori theory over empirical field observations.

Our analyses, grounded in high-resolution, validated datasets, and empirical observations, demonstrate the stability of the shorelines and the preservation of archaeological materials over extended timespans, directly contradicting Larcombe et al.'s assertions.

Larcombe et al.'s reliance on flawed datasets and speculative reasoning not only weakens their critique but also detracts from the broader objective of enhancing our understanding of submerged landscapes and archaeological processes. Future efforts should prioritize data validation, field observation and methodological rigour to avoid perpetuating the shortcomings highlighted in this response.

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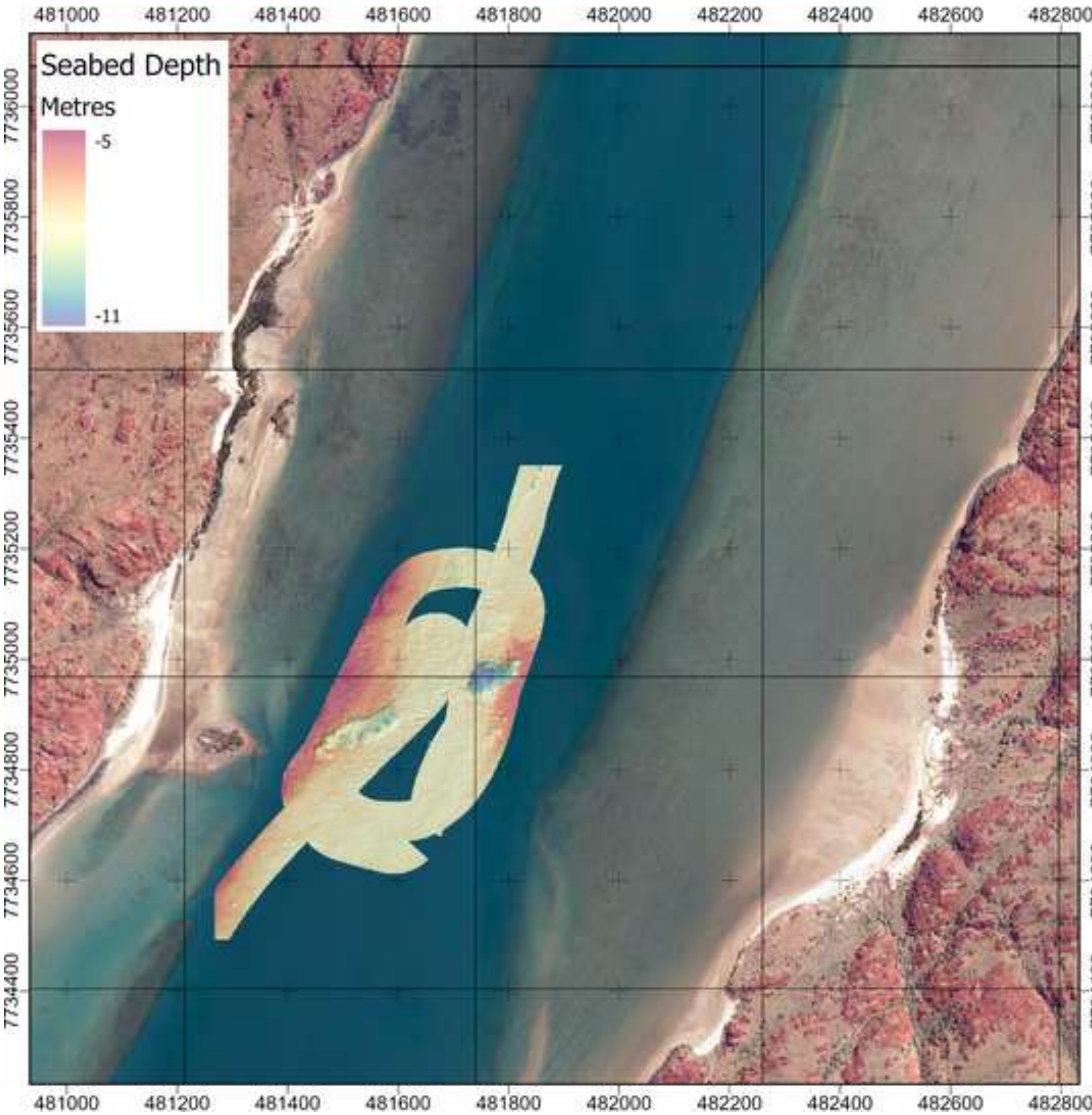
Figure 1 (Color)



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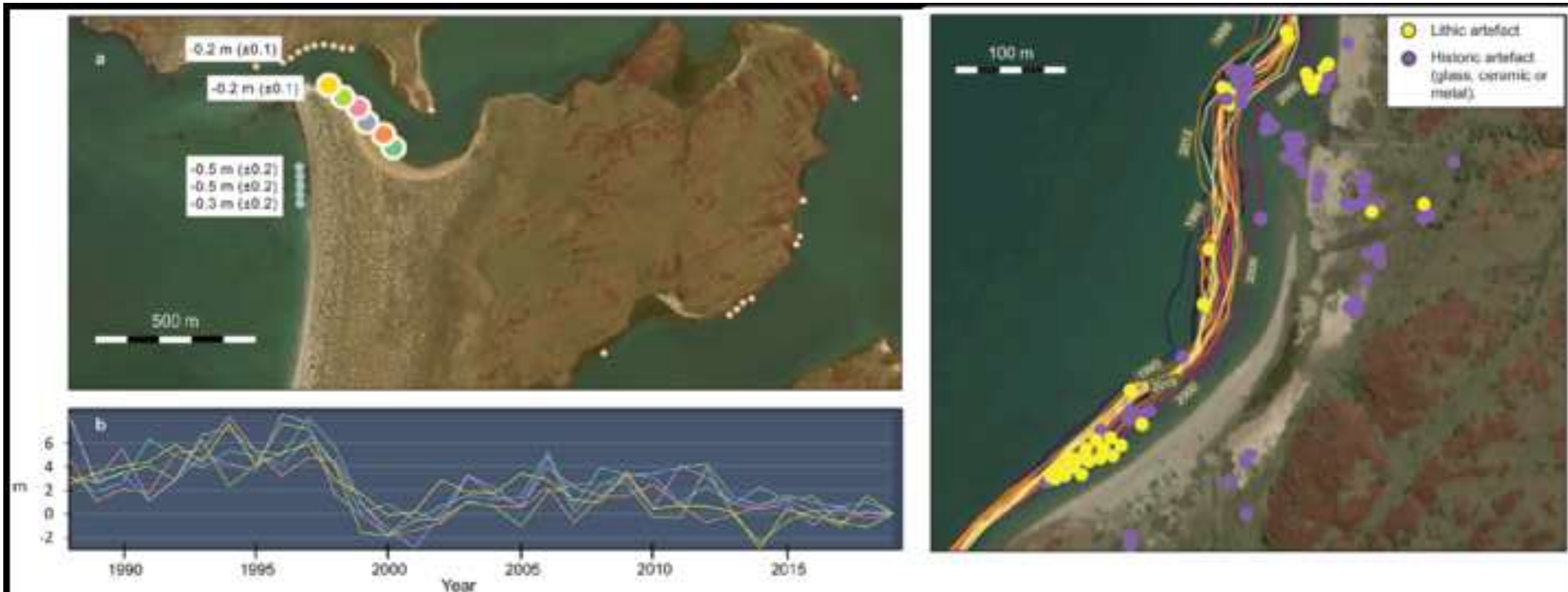

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Larcombe et al., Figure 13 [page 13]

Figure 3 (Color)

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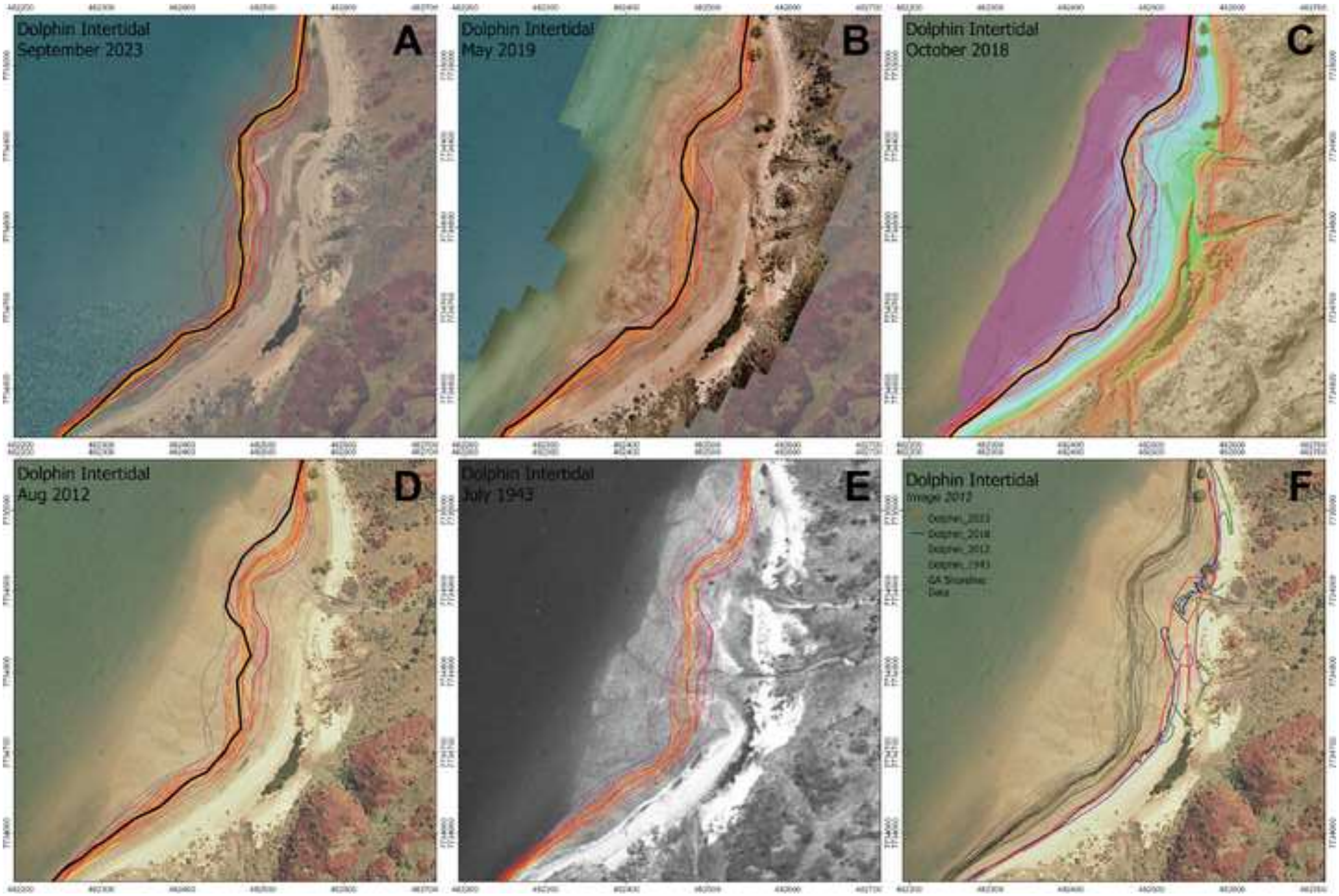

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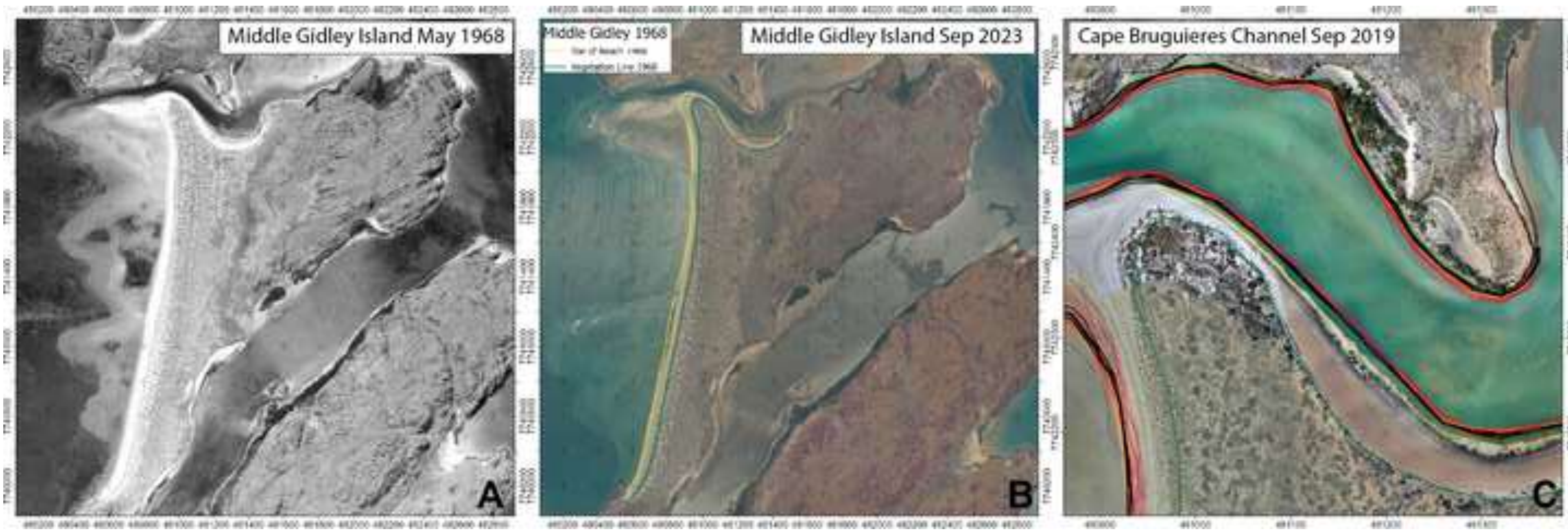

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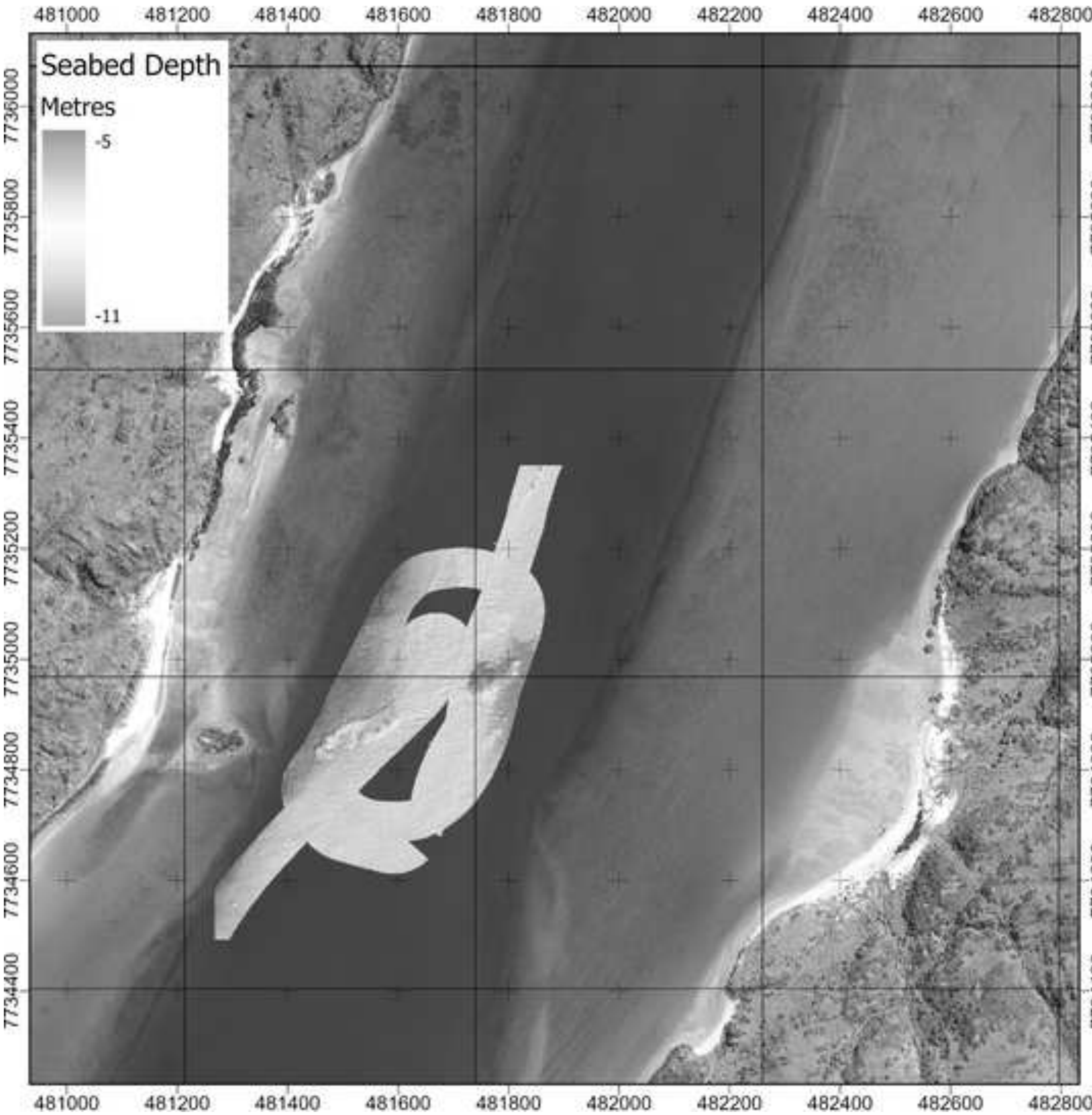

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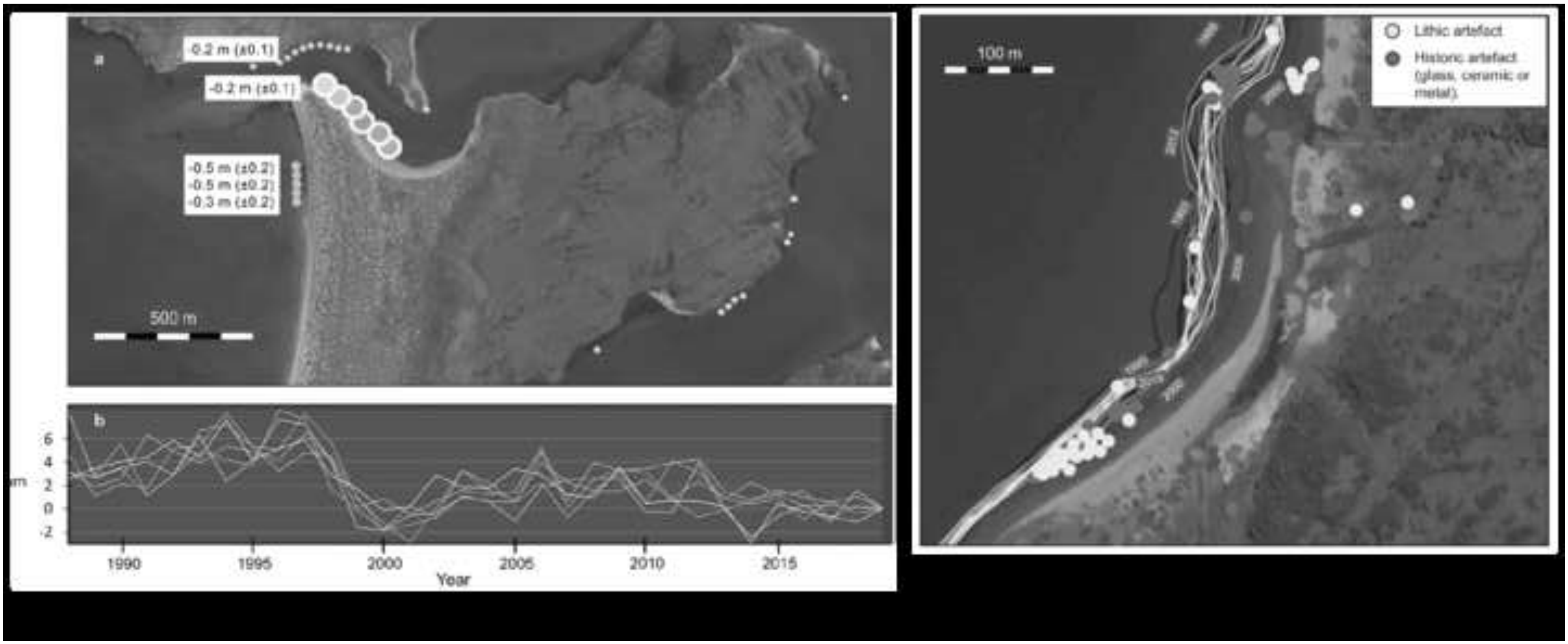

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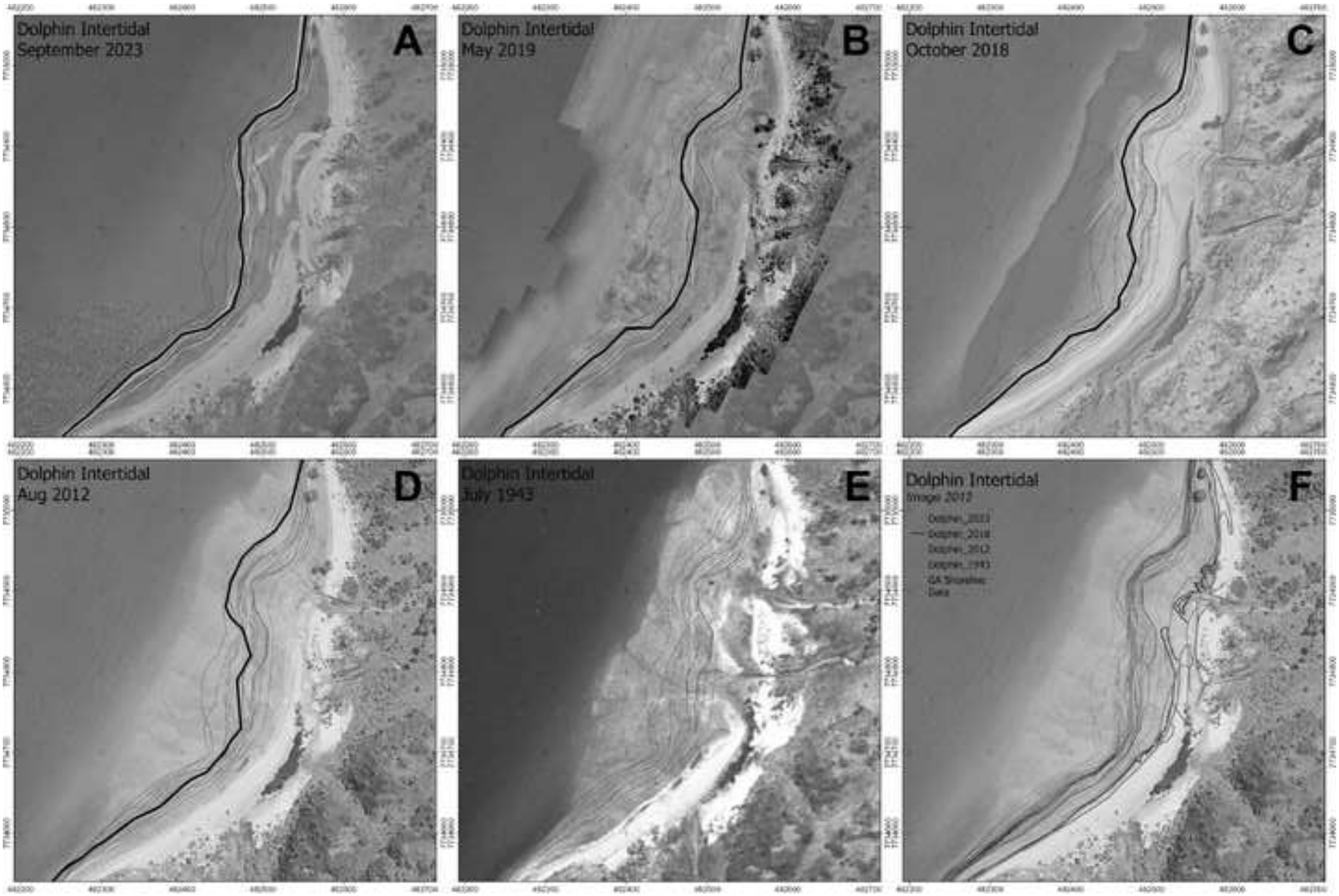

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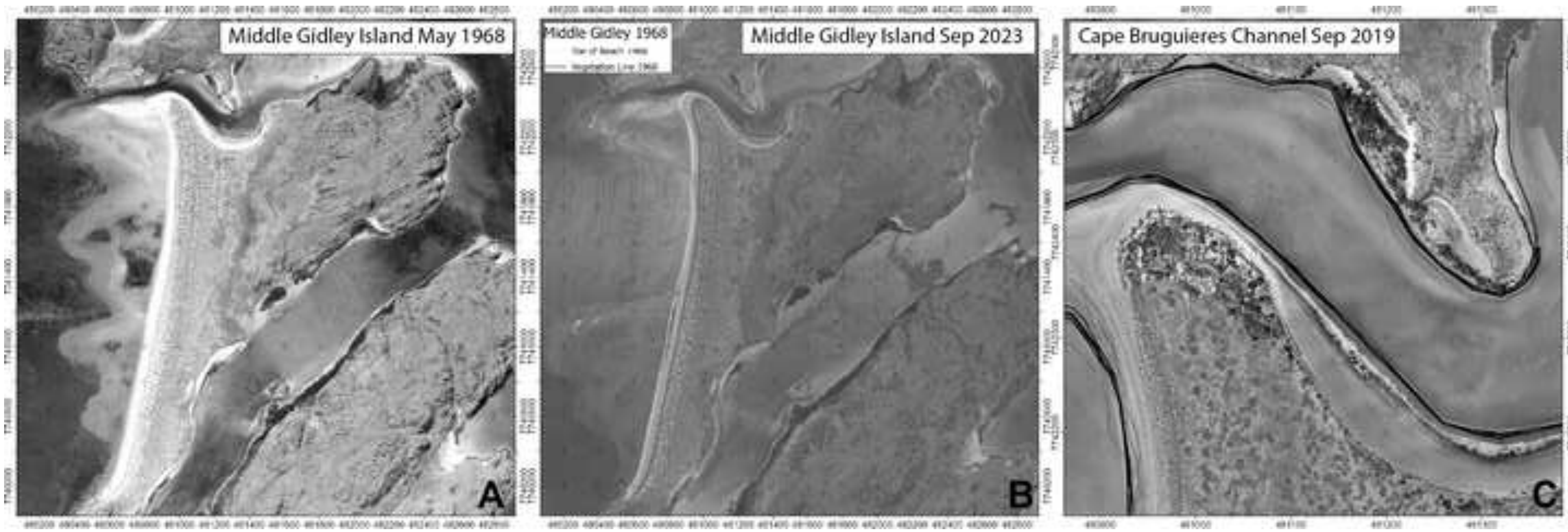

Declaration of interests

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