Endangered maritime archaeology in North Africa – the MarEA Project

Nikolaus, J., Westley, K., & Breen, C. (2023). Endangered maritime archaeology in North Africa – the MarEA Project. *Libyan Studies*, *54*, 1-16. https://doi.org/10.1017/lis.2023.4

DOI:
10.1017/lis.2023.4

Document Version
Publisher's PDF, also known as Version of record

Libyan Studies (2023), 1–16
doi:10.1017/lis.2023.4

Article

Endangered maritime archaeology in North Africa – the MarEA Project

Julia Nikolaus, Kieran Westley and Colin Breen
Ulster University, Coleraine, United Kingdom

Abstract

Increasing pressure – such as from conflict, climate change and urbanisation – on maritime cultural heritage in the Middle East and North Africa (MENA) led to the establishment of the Maritime Endangered Archaeology (MarEA) Project in 2019. This five-year programme aims to assess rapidly and comprehensively the vulnerability of maritime and coastal heritage in the MENA region and assist in its management in the face of the aforementioned challenges. The two case studies discussed in this article highlight some of the main aspects of MarEA's current work in North Africa by focusing on two different aspects of the methodological approach used: first, the generalised but comprehensive damage and threat assessment, as applied to all sites, and demonstrated for the historic port of Suakin (Sudan); second, site-specific shoreline change assessment for the purpose of assessing the impact of coastal erosion, as demonstrated for the World Heritage Site of Sabratha (Libya).

علم الآثار البحرية المهددة بالانقراض في شمال إفريقيا - مشروع الآثار البحرية المهددة

جوليا نيكولاس ، كيران ويستلي ، كولين برين

أدت الضغوط المتزايدة - مثل النزاعات وتغير المناخ والتوسع الحضري المفرط – على التراث الثقافي البحري في الشرق الأوسط وشمال إفريقيا إلى إنشاء مشروع الآثار البحرية المهددة في عام 2019. يهدف البرنامج، و الذي يمتد لخمس سنوات، إلى تقييم سريع وشامل لمدى ضعف التراث البحري والساحلي في منطقة الشرق الأوسط وشمال إفريقيا والمساعدة في إدارته في مواجهة التحديات المذكورة أعلاه. تسلط دراستا الحالة اللتان تمت مناقشتهما في هذا المقال الضوء على بعض الجوانب الرئيسية لعمل المشروع الحالي في شمال إفريقيا، بما في ذلك تقييم الأضرار والتهديدات في سواكن (السودان) وتقييم تغير الخط الساحلي في صبراتة (ليبيا).

Introduction

The North African coastline stretches over 11,000 km, from the Atlantic shores of Morocco to Egypt's Mediterranean coast and along the western Red Sea coast from Egypt to Sudan. Over millennia, many peoples have settled here, or moved along those shorelines, leaving behind the remnants of their existence such as boats, ships, harbours, cemeteries, buildings, settlements, industrial installations and objects. Many of these elements can tell us about social, political and trade networks in the past (Broodbank and Lucarini 2019). In many places, intangible heritage has been passed down the generations, such as boat-building methods, fishing techniques or folklore and stories about the sea (Agius 2012). Despite this rich variety of near-shore and coastal cultural heritage, maritime archaeology is still an emerging discipline in many North African countries and does not get the scholarly attention it deserves, particularly regarding smaller sites and sites that are not of the classical period (Broodbank and Lucarini 2019; Fenwick 2020; Knodell *et al.* 2022; Stone 2014). Unfortunately, maritime heritage across the region progressively faces more damage and threat from natural and human factors, including: erosion caused by rising sea-levels and winter storms (Reimann *et al.* 2018; Vousdoukas *et al.* 2022; Westley *et al.* 2021); the direct and indirect effects of conflict; and urban, industrial and agricultural development (e.g., El Safadi *et al.* 2022; Nikolaus *et al.* 2022; Ray and Nikolaus 2022). This is a global issue; over the last few decades, coastal areas across the world have seen dramatic increases in population density. Today, over 60% of the world's population resides near the sea (Crowell *et al.* 2007). This relatively recent development is putting immense pressures on the surrounding natural and historic environment (Djouder and Boutiba 2017; Neumann *et al.* 2015; Small and Nicholls 2003). This is also true for North Africa. In Libya, over 80% of the population lives in the urban centres along the coast (Abubrig 2016); in Algeria, the largest cities, including Algiers, Oran and Boumerdès, are located at the coast; and in Egypt, development along its northwestern coast has created an almost uninterrupted 200-km-long urban sprawl of hotels and houses, from Alexandria all the way west to El Daaba and beyond (Masoumi *et al.* 2018; Ray and Nikolaus 2022). This pressure is frequently compounded by under-resourced heritage agencies which, in some cases, may also have little specialist maritime capacity, and/or may lack up-to-date inventories of coastal and maritime heritage.

As a response to the increasing pressure on maritime cultural heritage in the Middle East and North Africa (MENA), the Arcadia Fund commissioned the Maritime Endangered Archaeology (MarEA) Project in 2019: a five-year programme to rapidly and comprehensively document and assess threats to maritime and coastal archaeology. The project primarily uses openly accessible satellite imagery – including from both recent (e.g., Google Earth or Bing) and historic (e.g., declassified Corona) sources – published and archived reports and literature to identify and assess the condition of coastal and submerged cultural heritage (Andreou *et al.* 2020). The approach builds on the work pioneered by the Endangered Archaeology in the Middle East and North Africa (EAMENA) project (Rayne *et al.* 2017) and, like EAMENA, documentation results are uploaded to the open access EAMENA database https://database.eamena.org. The database is hosted online by the University of Oxford and is a custom implementation of the open-source Arches Project Cultural Heritage Inventory and Management software platform,

Corresponding author: Julia Nikolaus; Email: j.nikolaus@ulster.ac.uk

Cite this article: Nikolaus J, Westley K, Breen C (2023). Endangered maritime archaeology in North Africa – the MarEA Project. *Libyan Studies* 1–16. https://doi.org/10.1017/lis.2023.4

developed by the Getty Conservation Institute and the World Monuments Fund (archesproject.org; Rayne *et al.* 2017). MarEA has customised aspects of the EAMENA database to be compatible with maritime-specific requirements, notably by adding terms relevant to maritime archaeological sites to the existing EAMENA-controlled vocabularies and incorporating new data-documentation fields that better contextualise the maritime environment (e.g., wave and tidal regimes). Additionally, MarEA has developed a new Geoarchaeological Resource Model (GRM), which enables documentation of geological and geomorphological data that provides evidence of past coastal change, a key consideration in maritime archaeology given major fluctuations in sea level and coastal geomorphology over the past millennia (Andreou *et al.* 2022a).

The aim of this paper is to showcase some of MarEA's work in North Africa via two case studies. These are linked by a focus on endangered maritime archaeological sites, but contrast in that each case study demonstrates a different aspect of the MarEA approach. The first case study, from the historic harbour of Suakin (southeast Sudan), provides an example of a generalised threat and damage assessment. This is based directly on the standard documentation approach using a combination of satellite imagery assessment and literature review, the results of which are uploaded to the EAMENA database. The assessment is comprehensive in that it considers all site types within the area of study as well as all possible causes and consequences of threat and damage. Documentation results can be extracted for a single site, or as demonstrated here, for a cluster of sites constituting a large archaeological entity.

The second case study refines the scale of analysis to give more detail on a particular site – in this case the World Heritage Site of Sabratha (western Libya) – and a particular threat: coastal erosion. This threat is highlighted because it is specific to coastal archaeological sites and, alongside flooding, is likely to become more prevalent in future because of climate change driven by sea-level rise and changes in storm intensity and frequency (Vousdoukas *et al.* 2022). The work presented here, therefore, provides an example of how to obtain more detailed and quantified information on a specific threat. As such, it is necessarily more time-consuming than the standard documentation approach. Consequently, it has not been applied to all sites, but only where it has been deemed necessary, for instance owing to the potential severity of the threat (see also Andreou 2022a; 2022c; Westley *et al.* 2023).

Case Study 1: Damage and threat assessment at Suakin, Sudan

Methodology

MarEA's primary methodology of documenting and assessing the condition of sites uses satellite remote sensing and image interpretation. Where available, aerial photography and data from existing published and unpublished materials are also used to enhance our understanding of the sites and features (Andreou *et al.* 2020; Rayne *et al.* 2017). Threat and damage assessments focus on terrestrial, intertidal and submerged sites that are impacted by natural factors (such as erosion or vegetation growth) and human impacts (urban expansion and agricultural intensification). Sites are evaluated based on their location, function, archaeological interpretation and condition by using a controlled vocabulary. While the spatial and, in some cases, temporal resolution of freely available satellite imagery is now very high, there are some limitations as to what can be detected and interpreted. The very nature of the imagery, taken vertically from space, eliminates the detection of features that are only visible in profile. Dense vegetation cover can prevent the detection of sites and features, and reflection from water or turbid conditions prevents imaging of shallow submerged sites. Further limitations are presented by the difficulty of determining a given site's function from satellite imagery alone without ground-truthing. While it is possible to assess via satellite imagery if a site has been

Table 1. Definition values applied by the EAMENA database: a) definition of 'certainty'; b) definition of condition scale.

a) Certainty	**Definitions**
Definite	The investigator has no reason to doubt their identification and it is either confirmed by published sources/other imagery specialists or multiple imagery sources.
High	The investigator has little reason to doubt their identification; it may or may not be confirmed by published sources/other imagery specialists or multiple imagery sources.
Low	The investigator has considerable reason to doubt their identifications/interpretations. It is not confirmed by published sources/other imagery specialists or multiple imagery sources.
Medium	The investigator has some reason to doubt their identifications/interpretations. It is not confirmed by published sources/other imagery specialists or multiple imagery sources.
Negligible	The investigator has considerable reason to doubt their identifications/interpretations. The evidence may also be contradicted by published sources/other imagery specialists or multiple imagery sources.
Not applicable	The investigator has entered 'No visible/known' or 'unknown' and certainty does not apply.
b) Condition scale	**Definitions**
Good	A site or element shows virtually no evidence of active deterioration and appears to be structurally stable.
Fair	Site or element shows little evidence of active deterioration, or some features of interest are obscured by more recent additions/alterations; it appears to be structurally stable and shows small areas of disruption.
Poor	A site or element shows moderate signs of active deterioration and/or signs of moderate structural instability, and/or moderate areas of disruption and/or damage to the majority of the original features of interest is apparent; some significant features are missing, some features of interest remain.
Very bad	A site or element shows serious signs of active deterioration and/or signs of severe structural instability and/or large areas of disruption, and/or the majority of features of interest are so damaged as to be not surveyable or are missing.
Destroyed	A site or element has been impacted very severely and it no longer retains integrity or sound archaeological data. This includes demolished buildings unless foundations, basements etc. exist which are of interest, for which use very bad.
Unknown	The current condition of the site is unknown.

damaged or, indeed, destroyed, determining the site condition is often difficult (Table 1b). The inclusion of certainty values corresponding to the classification categories enables an objective and nuanced approach to site documentation (Table 1a).

To illustrate the process and outcomes of remote documentation, the historic port of Suakin (southeast Sudan) is used as a case study. A range of data was used, comprising:

1. Published literature (e.g., Bloss 1937; Mallinson *et al.* 2009; Rhodes 2011)
2. Unpublished material (e.g., Rhodes 2008)
3. Recent Very High Resolution (VHR: <1m) satellite imagery hosted on Google Earth (2002–2020).
4. Existing specialist databases (e.g., shipwrecks: https://www.wrecksite.eu)
5. Historic maps dating to the early twentieth century and hosted online at the Durham University Sudan Archive (https://libguides.durham.ac.uk/asc-sudan-archive/).

Geographic background

The coastline of Sudan runs from the disputed Halaib Triangle in the north to the Eritrean border in the south. The coastal plain is up to ca. 50 km wide and bordered to the west by the Red Sea Hills, a coast-parallel mountain range reaching >1000 m in elevation. The Hills form a barrier between the coast and the Nile River to the west, but are cut in places by valleys, seasonal watercourses (locally known as *khors*) and one large river: the Baraka, which discharges into the Red Sea at the Tokar Delta. The coastline is relatively linear with scattered elongated bays (*marsas*) (Hoang *et al.* 1996). Offshore bathymetry is characterised by a relatively narrow continental shelf which plunges rapidly to the depths of the Red Sea basin. There are, however, numerous coral reefs, shoals and islands, such as the Suakin archipelago, located off the Tokar Delta (Figure 1).

Remote documentation initially focused on the sites of Suakin, Aydabh and Badi; because they are known ancient harbours, and thus foci of maritime activity (Adam 2017; Breen 2013; Breen *et al.* 2011; Peacock and Peacock 2008). Documentation aimed to consolidate the scattered literature on each site into a geospatial form suitable for database entry and with enhancement via satellite imagery-based threat and condition assessment. Thereafter, assessment extended out to cover the wider area around each site and to other locations which may have evidence of maritime activity: for instance, offshore islands and natural harbours such as Dungonab Bay.

Historic background

Suakin harbour comprises a ca. 2-km-long narrow *marsa* which forms a break in the coastal coral reef. Inland, the inlet opens out into a sheltered lagoon which contains two islands: near-circular Suakin Island – the main historical settlement – and Condenser Island. Settlement also extended onto the Geyf: the mainland directly opposite Suakin Island (Figure 2; Bloss 1936; Rhodes 2011).

Textual references to Suakin appear from the tenth century onwards whilst archaeological excavation supports an initial occupation from, at least, the first half of the eleventh century (Breen *et al.* 2011). Throughout much of the second millennium Suakin was one of the region's primary ports, facilitating trade and the movement of peoples from Africa to the Arabian/Persian Gulf and further afield to South Asia. Goods traded included foodstuffs, animals, cloth, spices, gold, silver and slaves. The port was also an embarkation point for pilgrims, including Christian Abyssinians travelling to Jerusalem and North African Muslims to Mecca, but this was not the mainstay of the local economy (Breen *et al.* 2015; Forsythe *et al.* 2022; Mallinson *et al.* 2009; Peacock 2012).

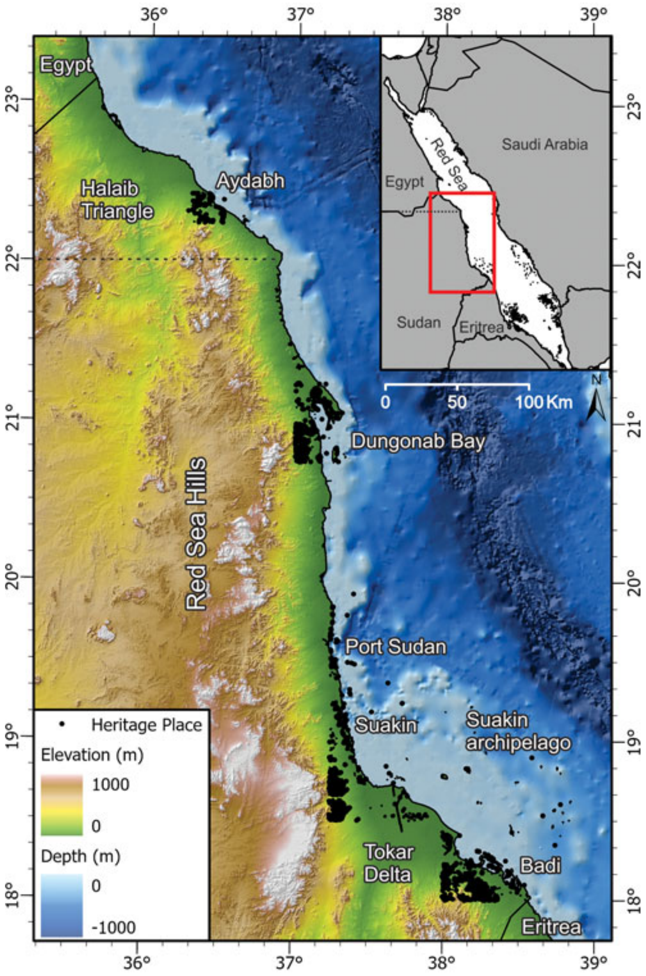

Figure 1. Topography and bathymetry of the Sudan coast with MarEA-documented Heritage Places (as of November 2022) overlaid (topography: Yamazaki *et al.* 2017; bathymetry: Gebco Compilation Group 2019).

Suakin was nominally under Mamluk control from the twelfth century and then Ottoman rule from the sixteenth century. Egyptian influence increased in the 1800s until it was officially ceded to Egypt in 1865 (Peacock 2012). The opening of the Suez Canal (1869) and Mahdist conflict (1881–98) brought with them greater British interest. From the 1880s onwards, Suakin became the British provincial headquarters and primary Red Sea port when they ruled Sudan as part of the Anglo-Egyptian condominium (Bloss 1937). However, following the establishment of Port Sudan harbour in 1909, Suakin declined to the point where it was effectively abandoned in the 1920s (Mallinson *et al.* 2009; Rhodes 2011).

Documentation summary

Being the core of the former settlement, Suakin Island was almost entirely covered by buildings or structures. Up to the sixteenth century these seem to have been mainly irregular structures with a number of contemporary stone buildings. Following the Ottoman takeover, more substantial numbers of stone (coral block) buildings were constructed, some of which remained in use (albeit renovated) up until the port's effective abandonment in the early twentieth century (Bloss 1936; 1937; Breen *et al.* 2011; Mallinson *et al.* 2009).

The island's perimeter served as the former quayside. Historic accounts suggest that, instead of using jetties, vessels moored

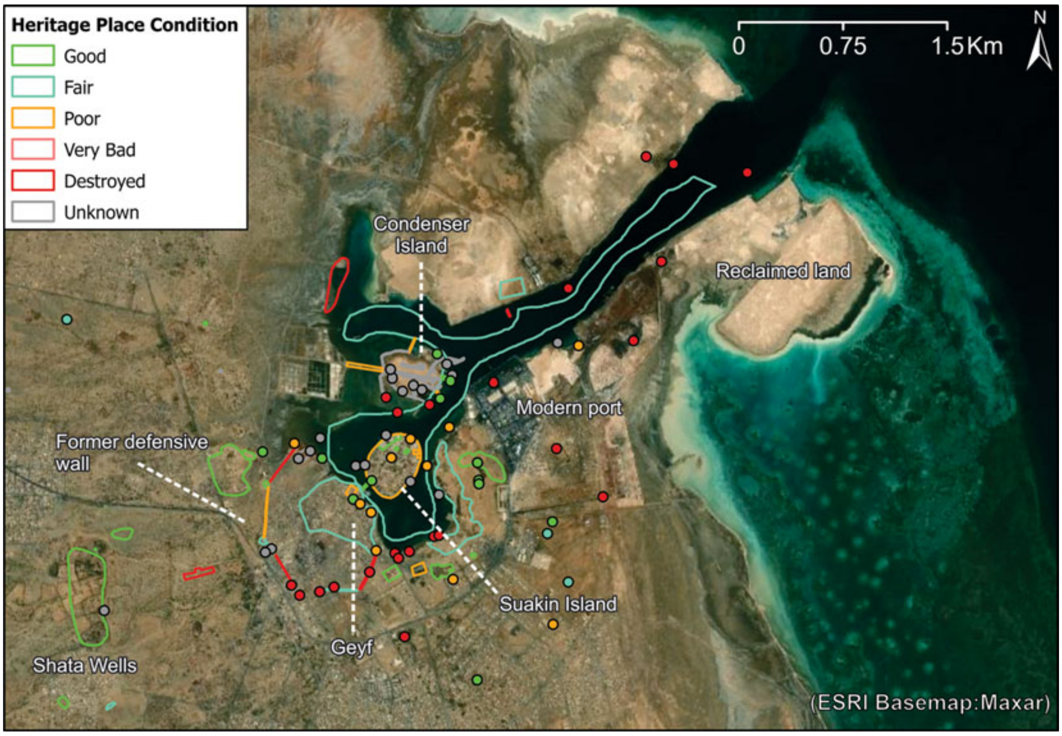

Figure 2. Recent satellite image (2022, courtesy of Maxar via the ESRI basemap) showing Suakin. Heritage places documented by MarEA are overlaid as points and polygons, which are colour-coded by their present-day condition (see online colour version for a clearer reading).

bow-to to the quay, and thence had direct access to the warehouses that lined its landward side (Mallinson *et al.* 2009). The presence of maritime infrastructure was confirmed by the archaeological excavation of an early (possibly sixteenth- to mid-nineteenth century) shore-parallel, coral-block quay wall which lies ca. 6 m inland of the modern shoreline. A later phase of quay construction during the Anglo-Egyptian period extended the island's circumference via a rubble, concrete and iron structure, which roughly corresponds with the modern shoreline (Mallinson *et al.* 2009; Rhodes 2008; 2011).

The Anglo-Egyptian period also brought further changes. Several piers and jetties were constructed on Condenser Island, with additional outlying piers on the mainland. These were built mainly for military purposes and were part of a programme of militarisation and fortification caused by Suakin's strategic importance. Condenser Island was the centre of military operations during the Mahdist conflict, the remains of which include the foundations of the military hospital, water condensers and narrow-gauge railway tracks (Bloss, 1937; Rhodes 2011). Suakin's mainland defences comprised a wall (initially earth, later upgraded to coral block and brick) connecting a series of forts surrounding the Geyf. Outside of this lay a further series of unconnected forts and redoubts (Bloss 1937; Rhodes 2011). Earlier Ottoman defences were presumably subsumed into this arrangement, or, in some cases (e.g., on the north side of the harbour), possibly dismantled into material for building the new fortifications (Mallinson *et al.* 2009). Other notable features outside the city included quarries, cemeteries (both Muslim and Christian) and wells, the latter essential, given that Suakin had no independent water supply (Bloss 1936; 1937; Peacock 2012; Rhodes 2011).

Underwater archaeological investigation has been limited but, even so, has identified debris relating to quay construction and use. In addition, several wrecks are identifiable from recent satellite imagery and historic aerial photos (Figure 3). These include two large metal wrecks off Condenser Island. One is the MV *Dasman*, a passenger ferry built in 1931, which caught fire and sank at her moorings in November 1970 (https://www.wrecksite.eu), but the name and origins of the second large wreck, which appears to lie partly over the *Dasman*, are unknown. The intermittently visible outlines of three smaller wrecks are also visible off Condenser Island – at least one of which is also visible on a 1930s aerial image – with two more such wrecks off Suakin Island.

Condition assessment

On Suakin Island, the key impact has been neglect and lack of maintenance following the port's abandonment. Even in the 1930s, shortly after abandonment, there were already calls for maintenance. By the late 1960s–early 1970s some buildings had fallen into ruin, whilst others were in a reasonable state (Hansen 1972). However, despite repeated calls for action, none was taken until post-2008 (see below). Consequently, by the 2000s, all the historic coral-block buildings lay in ruins (Figure 4; Breen *et al.* 2015; Salim 1997). This long-running issue was exacerbated by a lack of funds – heritage was not a priority for the national government – and ownership disputes. Many properties on the island are privately owned, thus ineligible for government spending. On the other hand, their classification as antiquities sites prohibited their owners from repair or reconstruction work (Ashley *et al.* 2015).

Since 2008, reconstruction work funded by the Turkish government has been undertaken; specifically, the rebuilding of the Customs complex and Hanafi and Shafai mosques (Figure 5). This is clearly visible on satellite images, as is the appearance of other structures and construction material, probably reconstruction related. However, this has been controversial, reportedly involving levelling of original buildings with minimal archaeological recording, as well as re-use of material from other protected structures in the reconstruction (Ashley *et al.* 2015; Breen *et al.* 2015).

Additional disturbances are related to the revival of Suakin as a working harbour, with modern port facilities built in 1991.

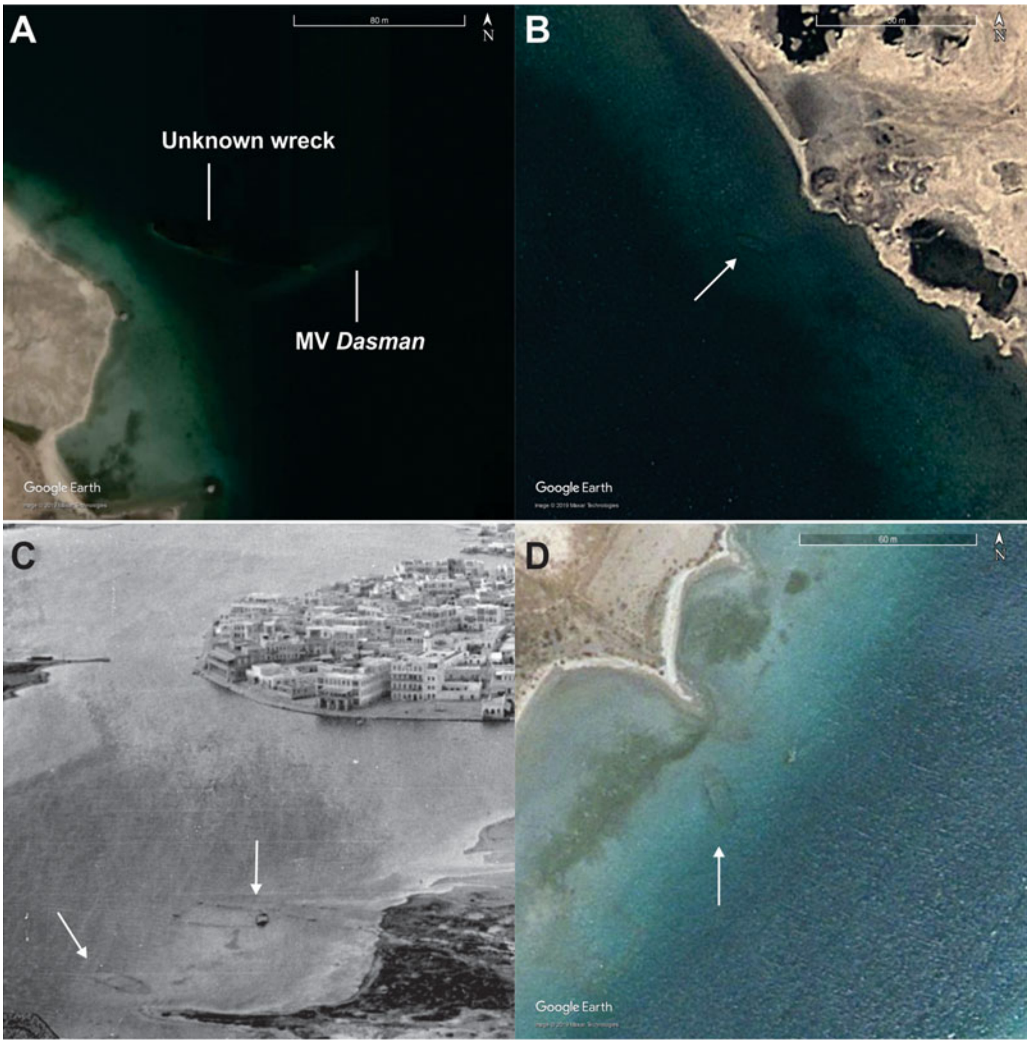

Figure 3. Wrecks in Suakin harbour. A) Wreck of the MV *Dasman* and another unidentified metal ship off northeast Condenser Island (Google Earth: 2018). B) Faint oval outline indicating a small, submerged wreck east of Suakin Island (Google Earth: 2010). C) 1930 oblique aerial photo looking southeast over Suakin Island with the shore of Condenser Island in the foreground (Durham University Sudan Archive, from Breen *et al.* 2011). Two wrecks are visible on the foreshore off Condenser Island. D) The larger of the two aforementioned wrecks is still visible on satellite imagery (Google Earth: 2009, Base map via Google Earth Pro © 2023 Maxar Technologies).

Satellite images also show that this was further upgraded from the mid-2000s onwards. This has resulted in extensive shoreline modification, particularly on the outer parts of the approach channel, where major reclamation was carried out. Suakin Island has not been directly affected, but the mainland shore to the southeast (encompassing part of the Geyf) was extensively modified from 2009–10 onwards, as was the north of Condenser Island. On Condenser Island, this has buried/removed several late-nineteenth-century, military-related structures and encroached on one shallow shipwreck. In the southeast, several jetties have been removed or buried by the reclamation and former quarries may also have been infilled. Large container trucks now also encroach on the possible remains of one of the forts (Figure 6).

Alongside this has come settlement expansion to the south and southwest of the historic settlement (Ashley *et al.* 2015). The defensive wall on the mainland has been largely demolished except for short, upstanding sections around the Kitchener Gate (main entrance to the town, itself partly renovated) and low banks or soil marks on the southern and northern sides of the city. Satellite images show that many of the forts have also been destroyed or lie in disrepair (see also Rhodes 2011). Nevertheless, some are still evident, including two forts on the inner wall, at least three of the outlying forts, and various low mounds or soil marks which could mark the footprint of demolished forts or redoubts. The more extensive anthropogenic modification/destruction of archaeological material on the mainland compared with the island has come about because much of the former has no legislative protection (Ashley *et al.* 2015).

Wider patterns

Outside of Suakin and the other assessed ancient harbours, patterns have started to emerge in the broader coastal Sudanese landscape. For instance, Dungonab Bay was described as a traditional pearl fishery (Burkhardt 1819) and was later the site of an early-twentieth-century, experimental pearl farm (Millward 1946). There are also intriguing hints of shell middens in this area, described as ancient by Crossland (1907; 1911), though this has yet to be fully investigated. The size of the grid squares used by MarEA/EAMENA to guide the assessment procedure (Rayne *et al.* 2017) also means that locations up to ca. 25 km inland were assessed, effectively capturing the coastal plain from the foothills of the Red Sea Hills to the sea. It is in the foothills and upper parts of seasonal watercourses that the highest density of sites has been documented, principally in the form of circular, ring-shaped, or sometimes more complex, stone-built cairns and tombs, locally known as ekratels. These structures, possibly dating

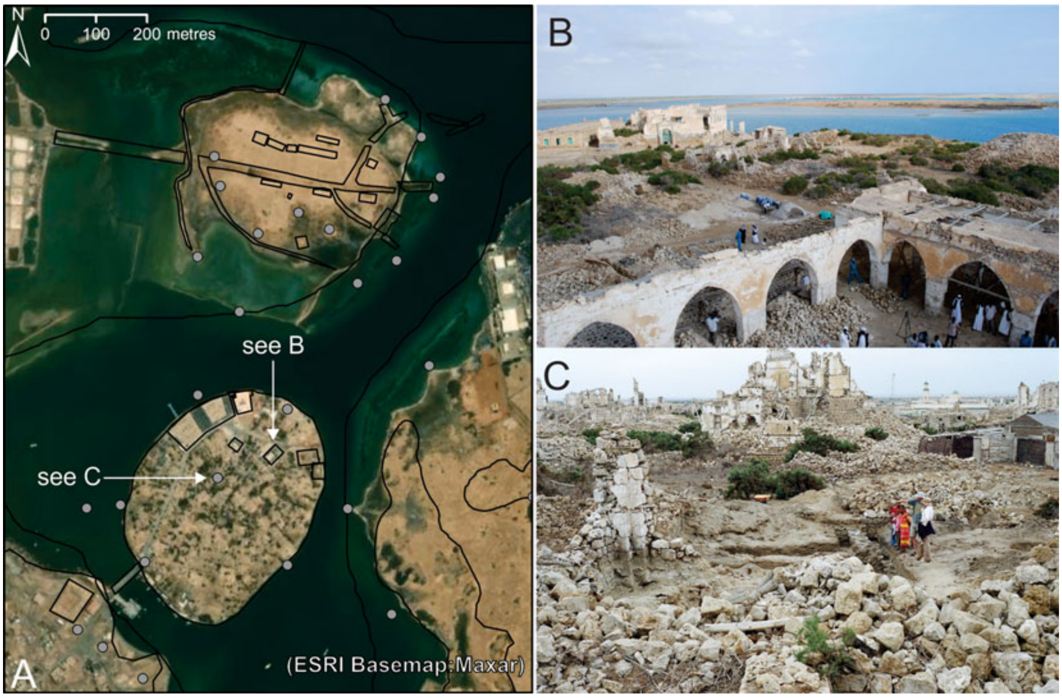

Figure 4. A) Recent satellite image (2022, courtesy of Maxar via the ESRI basemap) showing detailed documentation (grey dots, black lines) at Suakin and Condenser Islands. B) View looking north from the Shafai Mosque to Condenser Island. Note the ruined state of the mosque and surrounding buildings (photo: 2009, C. Breen). C) Ruins of the Beit al-Pasha and surrounding buildings in the centre of the Suakin Island (photo: 2006, C. Breen).

to the medieval/Islamic period (sixth to seventeenth centuries AD) and earlier, have previously been recognised (Adam 2017; Delany 1952; Magid *et al.* 1995; 1997). However, they have not been studied in detail or, to the best of our knowledge, systematically mapped at high resolution such as has been done for the MarEA documentation. For the most part, the landscape outside the major population centres is sparsely inhabited. Anthropogenic threats and disturbances are therefore limited to occasional examples of roads, tracks or mining/quarrying activities. Natural threats and disturbances are also present: for example, valley-side sites can and do experience erosion via seasonal flooding and/or slope failures.

Summary

Overall, aside from decay and lack of maintenance, most disturbances have been anthropogenic; primarily from building and development and infrastructure. Similar threats are likely to continue in the future in light of renewed investment in Suakin and particularly if pre-development mitigation is absent or minimal (especially for sites without legislative protection). For example, in 2017, Turkey was granted a 99-year lease for Suakin Island, which included the promise of rebuilding the Ottoman ruins for tourism and construction of a naval base (Akca 2019; Kabandula and Shaw 2018). Additional Qatari-funded port development was announced in 2018 (Vertin 2019). The current status of these projects is unclear; they may now be stalled since the 2019 political crisis in Sudan (Tanchum 2021; Vertin 2019). Nevertheless, they show the attractive nature of this unique and historic site for developers.

By contrast, the other ancient harbours of Badi (in use seventh to twelfth centuries AD: Kawatoko *et al.* 1993) and Aydabh (ninth to fifteenth centuries AD: Peacock and Peacock 2008) are much more remote. Consequently, they have not experienced the same level of impact from development or infrastructure. Their primary threats and disturbances are largely natural processes of weathering, although given their low-lying, coastal locations, it is probable that enhanced flooding or erosion caused by twenty-first-century sea-level rise will begin to affect them in the near future.

Case Study 2: Shoreline change assessment, Sabratha, Libya

Over the twenty-first century, flooding and coastal erosion is projected to increase as a result of sea-level rise driven by climate change (IPCC 2019; Mentaschi *et al.* 2018; Vousdoukas *et al.* 2018; 2020). This will, in places, be exacerbated by anthropogenic actions such as sand mining, upstream damming, canalisation of rivers/wadis and urbanisation, all of which can lead to a reduced supply of coastal sediment (Hzami *et al.* 2021). Consequently, there is a real risk to coastal archaeological sites and features (Brooks *et al.* 2020; Gregory *et al.* 2022). In the last few years, there have been important large-scale studies of risks to heritage along the African and the Mediterranean shores, which highlight the relative vulnerability of North Africa (Reimann *et al.* 2018; Vousdoukas *et al.* 2022). However, there are still relatively few studies that deal with specific regions and site-level case studies due to the lack of appropriate baseline data or interest in the North African coast. Here we provide an example of a more detailed case study focused on the World Heritage Site (WHS) of Sabratha, and a specific threat: coastal erosion.

Sabratha is located in western Libya in the province of Tripolitania between Tripoli in the east and the modern Tunisian border to the west. Its low-lying coastline is generally sandy and shallow, and the environment is essentially arid. The location of the settlement and port was determined by the presence of a sheltered anchorage which, over time, developed into a thriving harbour (Yorke 1986). The earliest evidence of occupation dates to the fifth century BC, with evidence of buildings between the seashore and the area that was later the Roman forum. The layout of this Phoenician settlement was restructured during the Roman period from the first century AD onwards, obliterating whole sections of the older parts of the city (Kenrick 1986, 8).

Figure 5. Satellite imagery (Google Earth 2009: Base map via Google Earth Pro © 2023 Maxar Technologies) showing the Customs complex, Muhafaza and two mosques on Suakin Island. The 2002 image shows the area largely in ruins, with the possible exception of the Hanafi mosque. The 2009 image highlights the collapse, or possibly pre-construction demolition, of parts of the Muhafaza and Shafai mosques. The 2018 image shows the newly reconstructed mosques and Customs complex, with the Muhafaza still a work in progress. Note also new buildings, probably associated with construction, and dumping of probable construction material.

Sabratha developed into an important trading centre, exporting goods from its hinterland and from sub-Saharan Africa into the wider Mediterranean world via its port. Furthermore, the town also appeared to have had a flourishing industry in fish-processing and purple dye (from *Murex trunculus* shells), evidenced by numerous vats located between the city's shore and the forum, as well as the presence of deliberately crushed *Murex* shells as an aggregate in mortar floors (Wilson 1999). Its harbour consisted of outer sea defences, including a natural reef that was capped by concrete, probably topped by a small building (Yorke 1986, 243). A long breakwater of boulders ran southeast from the western island (Dallas and Yorke 1968). Along the sea front by the Seaward Bath, large blocks and Cipollini columns, now submerged, indicate the existence of a quay, perhaps with porticoed buildings and/or warehouses, comparable to those at Lepcis Magna (Dallas and Yorke 1968). A second quay made of cut blocks was located to the west in a small bay, together with many parallel rock-cuttings. The remains of a circular building towards the west may indicate the existence of a lighthouse, situated at the end of the Byzantine wall (Dallas and Yorke 1968). A number of classical-period buildings are situated along the modern seashore, including the Temple of Isis, the Seaward Bath, the Oceanus Bath, the Basilica of Justinian, churches, as well as numerous vats and basins, and foundations of other buildings and warehouses (Figure 7).

Sabratha is often held up as an example of a site which is highly vulnerable to erosion and flooding on account of its low-lying elevation (0.4–7.5 m above present sea level) and proximity to the shoreline, with some structures clearly eroded in the past and others presently lying in the sea and intertidal zone (Bennett and Barker 2011; Brooks *et al.* 2020; D'Urso *et al.* 2015; El-Shahat *et al.* 2014). A sea wall was built in the early 2000s to protect the western part of the site (Baccar and Souq 2007; UNESCO 2000). Broad-scale modelling has also identified Sabratha as particularly vulnerable to future flooding and erosion enhanced by climate change (Reimann *et al.* 2018; Vousdoukas *et al.* 2022). Despite this, recent State of Conservation Reports for the WHS do not discuss erosion in detail. Only one of the last four reports mentions coastal erosion (and only in general terms: UNESCO 2018), whilst the others are more concerned with conflict, weathering, boundary issues and vegetation growth as the most immediate threats (UNESCO 2017; 2019; 2021). Given the significance of the site, and the potential for it to be damaged by coastal processes, it is worth examining in detail to identify past spatio-temporal trends in coastal erosion damage, which may give indications as to the site's future.

Methodological background

Shoreline change assessment relies foremost on the identification of shoreline proxies (e.g., instantaneous waterline, backshore cliff) from maps, aerial images or topographic surveys, which were acquired or created at different times. Digitised shoreline proxies can then be compared in Geographical Information Systems (GIS) to determine the rate and pattern of shoreline movement (i.e., coastal erosion or accretion) over time and space (Moore 2000; Thieler and Danforth 1994). The approach is well established in coastal management and geomorphological studies and has also been adopted by archaeological vulnerability assessments (Hil 2020; O'Rourke 2017; Westley 2019).

For this study we use two types of imagery. First is an overview of Sabratha and the adjacent coastline using medium spatial resolution (30 m) Landsat imagery. The advantage of Landsat is that it is open-access, has high temporal resolution and a time series back to the mid-1980s. Its disadvantage is its spatial resolution which restricts it to detecting changes of several metres to a few tens of metres. Nevertheless, this enables a general characterisation of coastal change since the mid-1980s (see also Castelle *et al.* 2021; Luijendijk *et al.* 2018; Mentaschi *et al.* 2018; Vos *et al.* 2019). Second is a detailed assessment of the site itself using historic aerial images and recent Very High Resolution (VHR: < 1m spatial resolution) satellite imagery. Such images enable detection of shoreline changes of less than a few metres. However, VHR imagery is often only available at cost from commercial providers, and at more intermittent time intervals, particularly before the 2000s.

Methodology: Landsat shoreline extraction

Annual composite shorelines for the period 1985–2021 were extracted from Landsat imagery following Luijendijk *et al.* (2018). Such shorelines represent the land-water interface (waterline) generalised from multiple individual shorelines for a single year. They were used because they: 1) smooth out the effect of waves and tides on the instantaneous waterline; 2) account for variations in waterline position caused by low resolution of the

Figure 6. Comparison of Google Earth imagery from 2002 and 2019 (Base map via Google Earth Pro © 2023 Maxar Technologies). Note the subsuming of up to 5 piers/moles by land reclamation. Redevelopment associated with reclamation has also removed former quarries on the southeast side of the lagoon. Those further north, a former fort and an Islamic cemetery remain largely unaffected but are increasing encroached upon by the development. Also evident are a new pier built onto the historic causeway linking the Geyf and Suakin Island, as well as new construction on the island's southern shore.

source imagery; 3) enable exclusion of cloud cover and; 4) reduce the number of extracted shorelines to a usable amount. Detection and extraction steps included (see Westley *et al.* (2023) for additional details):

1. Using Google Earth Engine (GEE: Gorelick *et al.* 2017), Landsat 5, 7 and 8 Collection 2 Surface Reflectance imagery from 1985–2021, which cover the study area, were filtered to exclude images with:
   - Low geolocation accuracy (Geometric RMSE >10m)
   - High cloud cover (>30%)
2. Two-hundred and ninety images, representing 25 years out of the full 36-year time series, met the above filter criteria. Filtered images were composited by year using a fifteenth Percentile reducer (Luijendijk *et al.* 2018) in order to further exclude cloudy, white water or sun-glint-affected pixels.
3. The dynamic thresholding approach of Donchyts *et al.* (2016) was applied to the composite images to extract the shoreline. Only composites created using >5 images were used.
4. Extracted shorelines were exported to GIS software where they were manually checked and cleaned to remove erroneous values (e.g., false shorelines caused by cloud shadows). A smoothing function was employed to reduce their pixelated appearance.

Methodology: VHR image shoreline extraction

Two types of VHR image were used: first, satellite images from the last decade extracted from Google Earth (GE); second, archive vertical aerial images collected in 1943 over the site (see Table 2). It was necessary to use GE because of the commercial cost of obtaining orthorectified VHR imagery. Although GE has been used for shoreline mapping (Warnasuriya *et al.* 2018; 2020), it has accuracy issues which must be accounted for. For instance, GE provides no metadata on georeferencing quality, level of orthorectification or original image resolution (Goudarzi and Landry 2017; Potere 2008), all factors which influence the accuracy of the detected shoreline proxy (Anders and Byrnes 1991; Moore 2000). This is evident in that successive images in time often do not perfectly align on the GE interface. To remedy this, images were extracted from GE at a constant zoom level (altitude 600 m), imported into GIS software and manually co-registered to the Google Satellite base map, chosen because of its clarity over the study area. Extracted GE images were then checked for

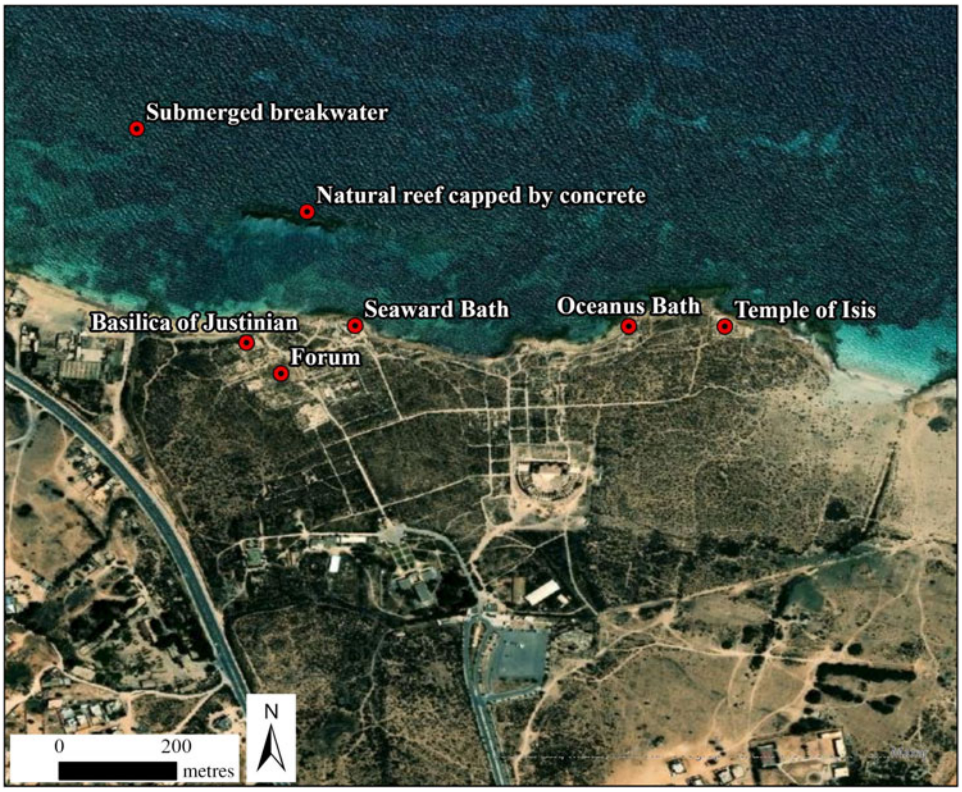

Figure 7. Google Earth imagery of Sabratha, indicating the location of buildings and features mentioned in the text (Base map via Esri ArcGIS Pro, Maxar, Earthstar Geographics).

alignment with each other and the base map using the same set of control points (e.g., road intersections). In this case, only one set of images (2011) required a linear shift of ca. 2 m to align. All other extracted sets had good alignment; <1 m for each of the reference features. The 1943 aerial images were also co-registered to the Google Satellite base map using 7 to 16 control points and a second-order polynomial. Individual co-registered aerial images were subsequently merged into a single mosaic.

Shoreline proxies were identified from both the GE and 1943 images and manually digitised. We focused on areas where archaeological material is most likely to be exposed by erosion: cliff lines or scarps (indicated by clear cliffs or breaks in slope) and the transition between stable vegetated sediments and mobile un-vegetated sediments (indicated by the vegetation line seaward of the shore). These proxies were chosen because it is such locations where archaeological sites are often damaged; for instance, with material eroding out of formerly buried backshore sediments, or above-ground structures collapsing when the underlying sediment is eroded (e.g., Andreou *et al.* 2017; Westley 2019; Westley and McNeary 2014).

Methodology: Rate of change statistics

Rate of change statistics were calculated using the open-source Digital Shoreline Analysis System (DSAS) 5.1 add-in for ArcGIS 10 (Himmelstoss *et al.* 2018). DSAS works by digitally emplacing a series of shore-perpendicular transects across the extracted shorelines. Given that the time of each shoreline is known (e.g., from the image acquisition date), their intersection with the transects can be used to calculate the rate and distance of shoreline movement over time. DSAS parameters used are summarised in Table 3. Key statistics calculated were the Linear Regression Rate (LRR) and the End Point Rate (EPR). LRR gives the rate of shoreline movement based on a best-fit linear regression applied to all shoreline positions in a time series. It is, therefore, only suitable for time series with more than two shorelines. EPR gives the rate of movement between the earliest and latest

Table 2. Summary metadata for imagery used in the shoreline change analysis.

Area	Sensor/Provider	Date	Image resolution (m)
Wider Area	Landsat 5, 7, 8/ Google Earth Engine	1985–2021	30
Site	Worldview-2/Maxar-Google Earth	19/05/2022	0.5
Site	Worldview-3/Maxar-Google Earth	12/09/2021	0.5
Site	Worldview-2/Maxar-Google Earth	11/08/2019	0.5
Site	Worldview-2/Maxar-Google Earth	08/10/2017	0.5
Site	GeoEye-1/Maxar-Google Earth	14/07/2015	0.5
Site	GeoEye-1/Maxar-Google Earth	10/03/2013	0.5
Site	GeoEye-1/Maxar-Google Earth	20/08/2011	0.5
Site	Aerial frame camera/BILNAS archive	02/02/1943	At least 0.5

Table 3. Key DSAS parameters used in the shoreline change analysis. Two uncertainty values were calculated for the VHR imagery comprising the sum of the image spatial resolution (0.5m), a manual digitising error (0.75m, found by digitising the same proxy three times and taking the average difference) and a co-registration error (1.9m for 1943 aerials, taken from the calculated RMSE; 0 for the recent satellite imagery because alignment differences were minimal between successive timesteps, or required only linear shifting).

Shoreline Type	Transect spacing (m)	Uncertainty (m)
Landsat	50	±15
VHR	10	±1.25 (2011–22 satellite) / ±3.15m (1943 aerials)

shorelines in a time series and can therefore be used for time series with only two shorelines. In both cases, a 90% confidence interval was also used to quantify the uncertainty of the calculated rate (Himmelstoss *et al.* 2018). For Landsat imagery, LRR was calculated for all 25 shorelines in the time series. For the VHR imagery, LRR was calculated for all shorelines and EPR for two subsets: first, a 2011 versus 2022 subset which aimed to characterise shoreline change within the last decade; and second a 1943 versus 2011 subset which aimed to do the same, but for the period preceding the last decade.

Results: Landsat

Based on the Landsat imagery, the study area shows a roughly even spread between coastal retreat and advance (48% versus 50% of transects respectively) with maximum rates of movement reaching up to -1.4 m/yr for retreat and +0.6 m/yr for advance. However, the vast majority of the movement rates are low and fall within the 90% confidence intervals. Thus, it cannot be certain if these low rates genuinely indicate change or are simply caused by the uncertainties in the data, particularly resulting from the image resolution. That said, some areas do show clearer indications of advance and retreat. For example, the beach in the west of the study area shows a strong trend of retreat whilst advance is indicated for a small bay ca. 4 km west of the Sabratha WHS. This may be related to minor harbour works (e.g., pier construction), which are visible on satellite imagery. The WHS itself falls almost entirely within the stable/uncertain category. In other words, at this spatio-temporal scale, the shoreline at the WHS does not show any difference to the adjacent areas in terms of change, and destructive trends in erosion are hard to detect (Figure 8).

Results: VHR imagery

Assessment of VHR imagery shows clearly that the WHS site of Sabratha has experienced coastal retreat of up to −21.5 m since 1943. This translates to an average rate of retreat of −0.11 m/yr, with the maximum rate measured as −0.59 m/yr (Figure 9A). Importantly, even with 90% confidence intervals included, extensive stretches are still classified as retreat, supporting the view that this is genuine erosion and not a false detection stemming from image resolution and digitising errors. However, erosion is not consistent across the site. The greatest areas of retreat are in the western part of the site around the peninsula holding the Seaward Bath and running east to the headland at Church 4. This headland appears to have changed relatively little, but the shoreline to its east up to the Oceanus Bath has retreated extensively. In the eastern part of the site, around the Temple of Isis, there are hints of erosion, but also suggestions of stability (Figure 9A). Further patterns are evident if the VHR data are split into temporal subsets (Figures 9B and C). These indicate that the vast majority of erosion took place before 2011. Post-2011, there are only isolated spots of erosion; for most areas the calculated rate of shoreline movement lies within the 90% uncertainty bounds.

Closer comparison of historic images and site plans with recent satellite imagery also enables a qualitative assessment of damage/disturbance patterns. At the western-most part of the site, in the vicinity of the Seaward Bath, coastal erosion has clearly caused retreat of the backshore scarp. In the 1943 images the above-ground ruins are separated from the shoreline by a partly vegetated slope (Figure 10C). This was removed by 2011 and presently consists of a rocky foreshore exposed to waves (Figures 10A, B). Both the 1943 image and a site plan from 1948 also show that elements of the Seaward Bath and buildings at the former tip of the headland have been removed (Figures 10C, D). This area is now partly protected by a modern seawall built in the 2000s. However, further to the west and east, whilst erosion of the backshore cliff/scarp has occurred, it has largely not affected the upstanding remains, except perhaps those which lie east of the modern seawall. It is unclear whether this now-eroded slope contained any buried and undocumented archaeological material which has now been lost.

In the central part of the site between Church 4 and the Oceanus Bath, the backshore cliff retreated by several metres to tens of metres some time between 1943 and 2011 (Figure 11). Since then, though, its position appears to have remained stable (Figures 11A, B). This did not affect any visible above-ground structures save possibly the northeastern corner of Church 4 and the structures located to its north (Figures 11C, D). Even so, clear erosion here is hard to detect because the past and present cliff lines run very close to each other. Whether any buried material was destroyed by the extensive cliff erosion between

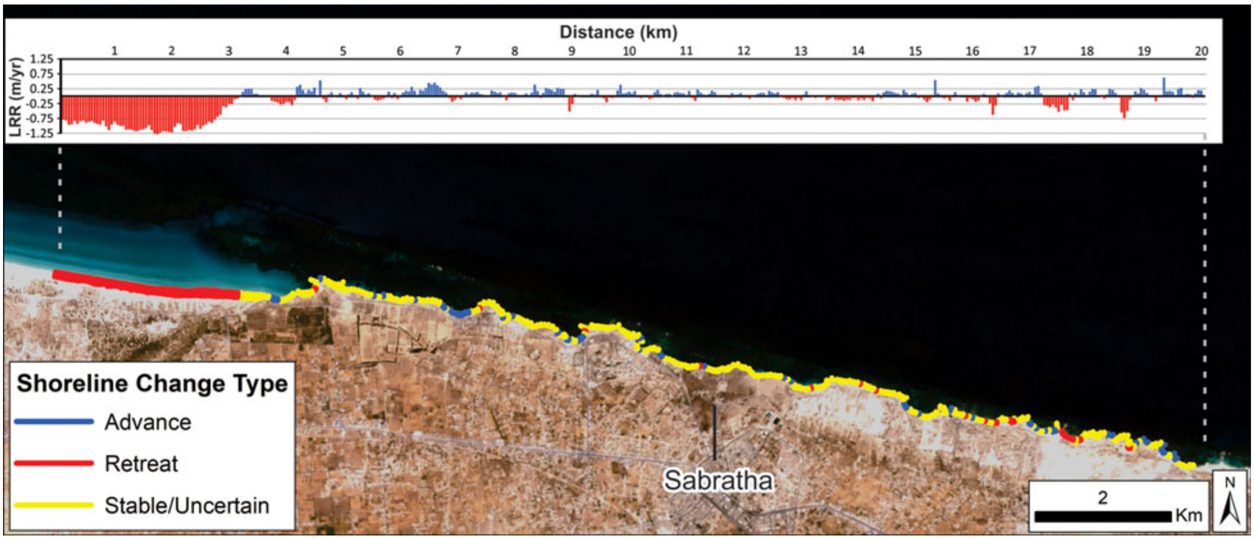

Figure 8. Classification of shoreline change transects into statistically significant categories based on LRR and 90% LCI from the 1985–2021 composite images for the area around Sabratha. LRR is plotted on the inset graph with negative values (red) indicating erosion/retreat and positive values (blue) indicating accretion/advance. The label Sabratha indicates the WHS. Basemap: Sentinel-2 (Copernicus Program; 2021 annual composite created using GEE) (see online colour version for a clearer reading).

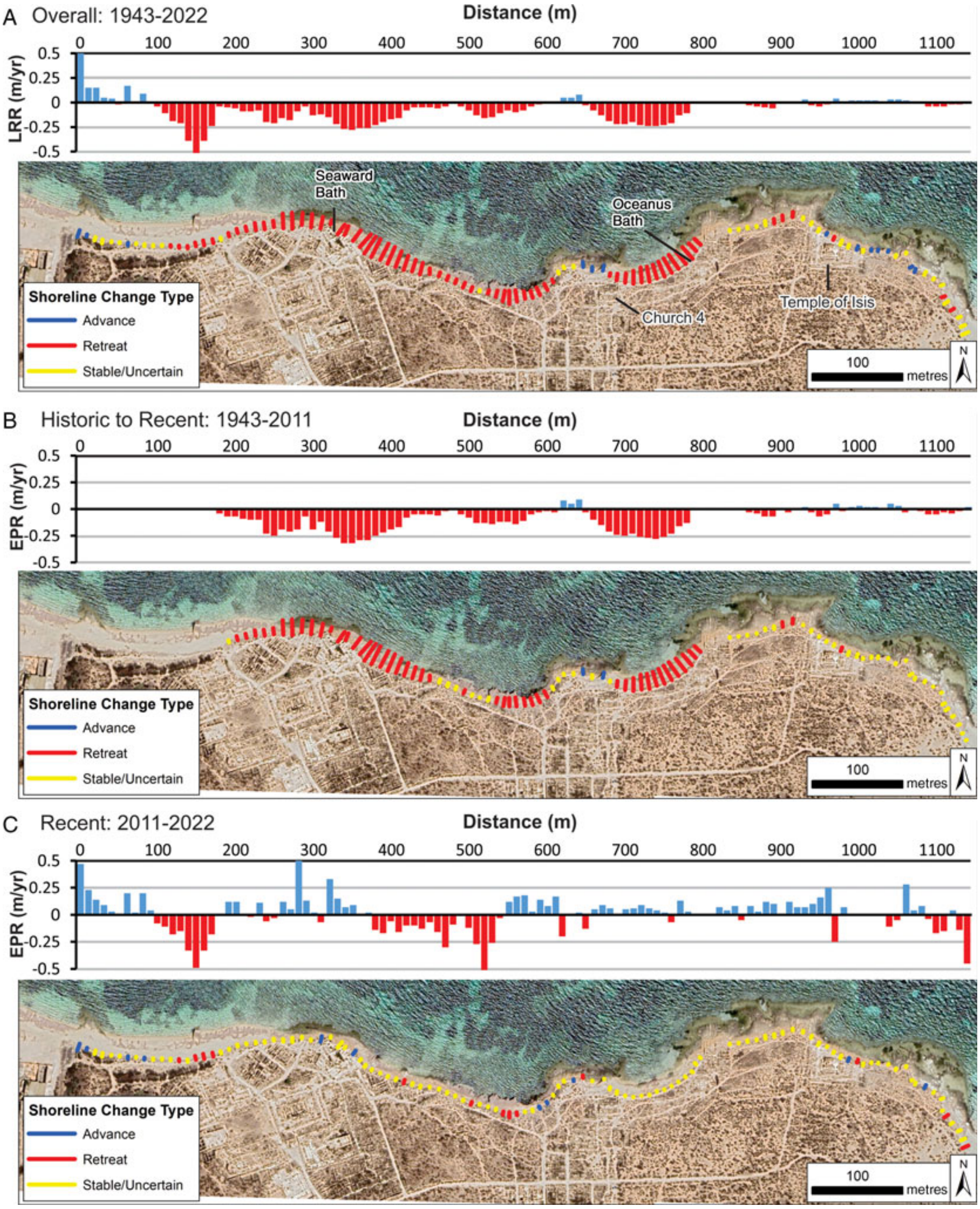

Figure 9. Backshore cliff line/vegetation line movement at the Sabratha WHS based on VHR satellite and historic aerial imagery. Coloured lines show transects classified into shoreline movement categories based on inclusion of 90% confidence intervals. A) 1943–2021 B) 2011–2022 and C) 1943–2011. Insert graph shows LRR of shoreline movement for A) and EPR for B) and for C). Negative values (red) indicate retreat, positive values (blue) indicate advance. Background satellite image is from 2022 (Maxar and Google Earth) (see online colour version for a clearer reading).

Church 4 and the Oceanus Bath is uncertain. One area which has been clearly affected by erosion is the complex of buildings north of the Oceanus Bath. These are presently located in the intertidal zone and within the reach of waves. Both the 1951 plan and 1943 image clearly show a large rectangular building with upstanding walls and, immediately to its east, several smaller adjoining structures. By 2011, the northern third of the large structure had been removed, as had the smaller structures. This area is currently characterised by a rocky or boulder-strewn (probably the collapsed blocks from these structures) foreshore. The ground plan of the features seaward of these structures is still very similar to that documented in 1951, but it is unclear from the satellite imagery whether the upper courses of the walls have been eroded down.

The eastern outskirts of the site include the Temple of Isis, a formerly rectangular complex of structures which has clearly been eroded in the past, as shown by the absence of a large chunk of its northeastern side (Figure 12A). However, the extent of post-1943 erosion is much less than at the locations previously discussed. The overall extent and shape of the ruins remains largely similar between 1943 and 2022 (Figures 12C, A). It is most likely that erosion has occurred in the central part of the Temple, where a section of cliff which protruded slightly in 1943–1951 has since been cut back. More certain evidence of erosion is located at the headland northwest of the Temple (Figure 12). Here the cliff has more visibly retreated, and walls which formerly protruded from the cliff are now much less apparent, particularly when compared to the 1951 plan (Figure 12D).

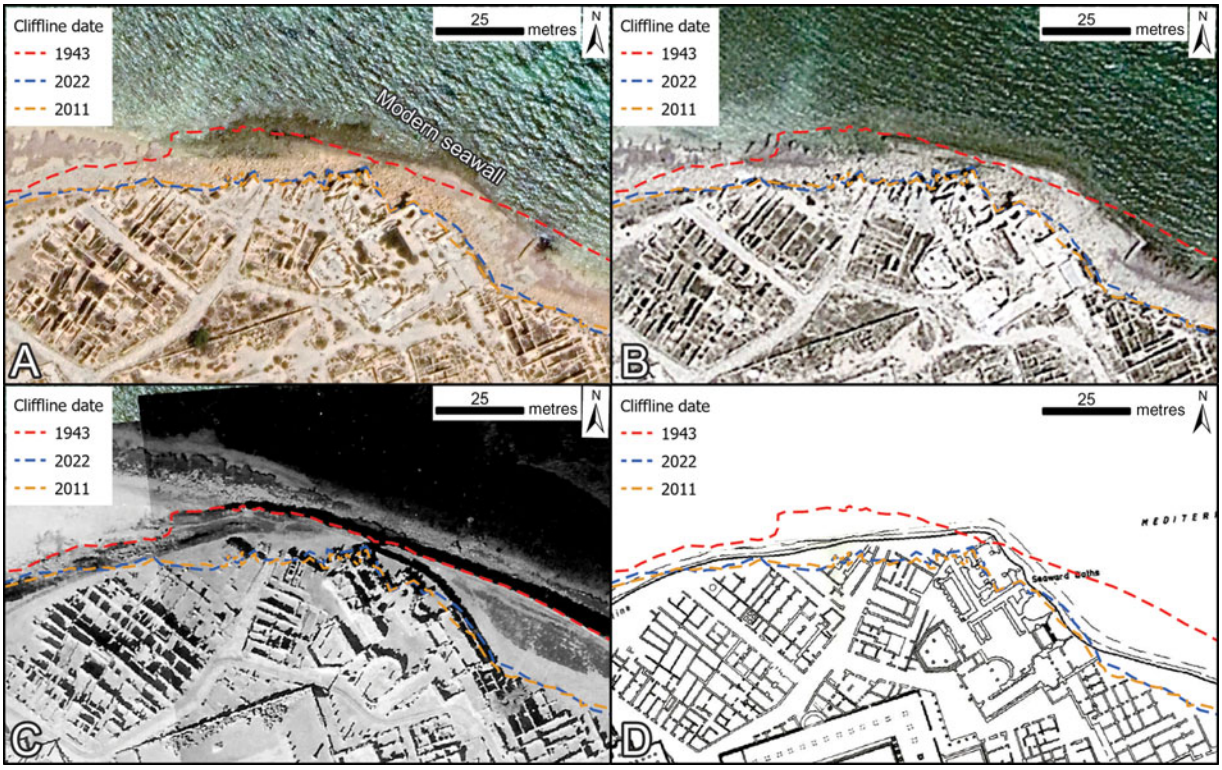

Figure 10. Area around the Seaward Baths at the Sabratha WHS at different time periods. A) 2022 GE VHR image; B) 2011 GE VHR image; C) 1943 aerial image (from BILNAS archive); D) site plan created in 1948 (from Kenrick 1986: Figure 123). Digitised shoreline proxies (vegetated cliff/backshore edge) are superimposed as coloured lines (see online colour version for a clearer reading).

As at the shore north of the Oceanus Bath, this area is now characterised by a rubble-strewn foreshore. Also, as in the previous area, features slightly further seaward (within the intertidal zone) still maintain the same ground plan as from 50–60 years ago, but the degree of collapse in their upper courses is uncertain (Figures 12A, D).

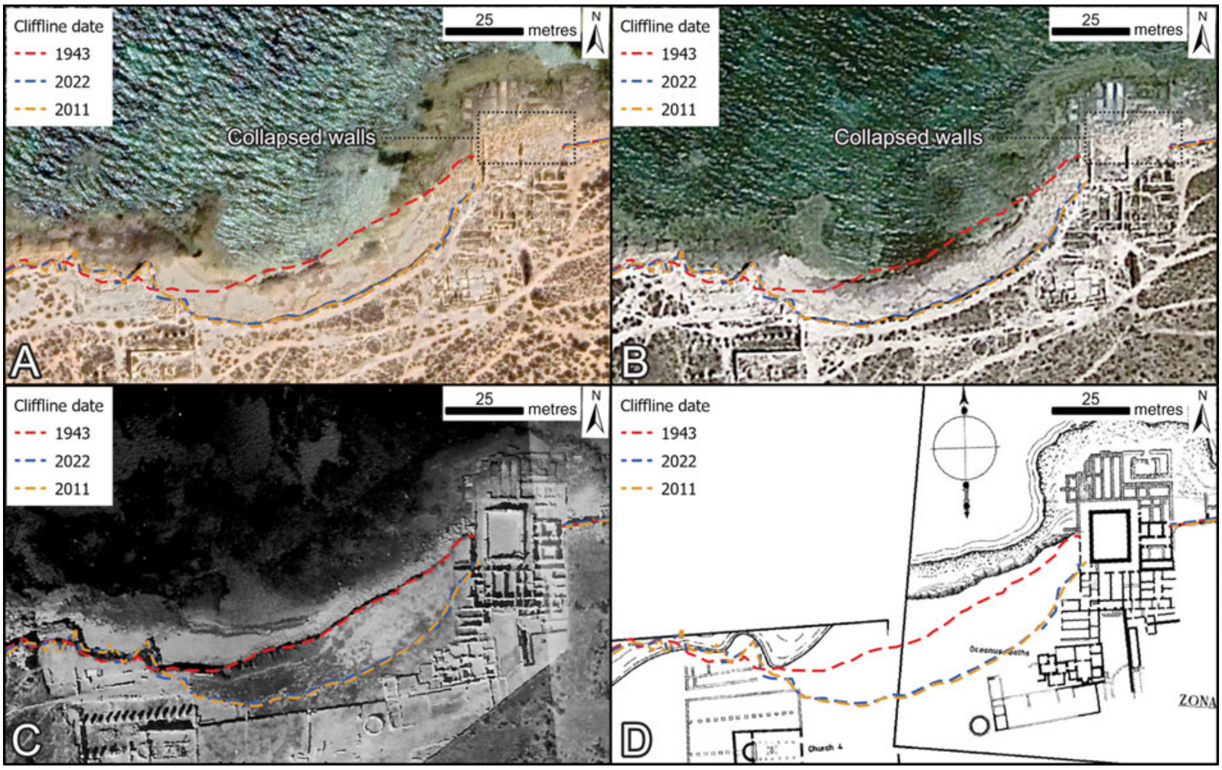

Figure 11. Area between Church 4 and the Oceanus Baths at the Sabratha WHS at different time periods. A) 2022 GE VHR image; B) 2011 GE VHR image; C) 1943 aerial image (from BILNAS archive); D) site plans created in 1948 (left side covering Church 4) and 1951 (right side covering Oceanus Baths) (from Kenrick 1986: Figures 124 and 125). Digitised shoreline proxies (vegetated cliff/backshore edge) are superimposed as coloured lines (see online colour version for a clearer reading).

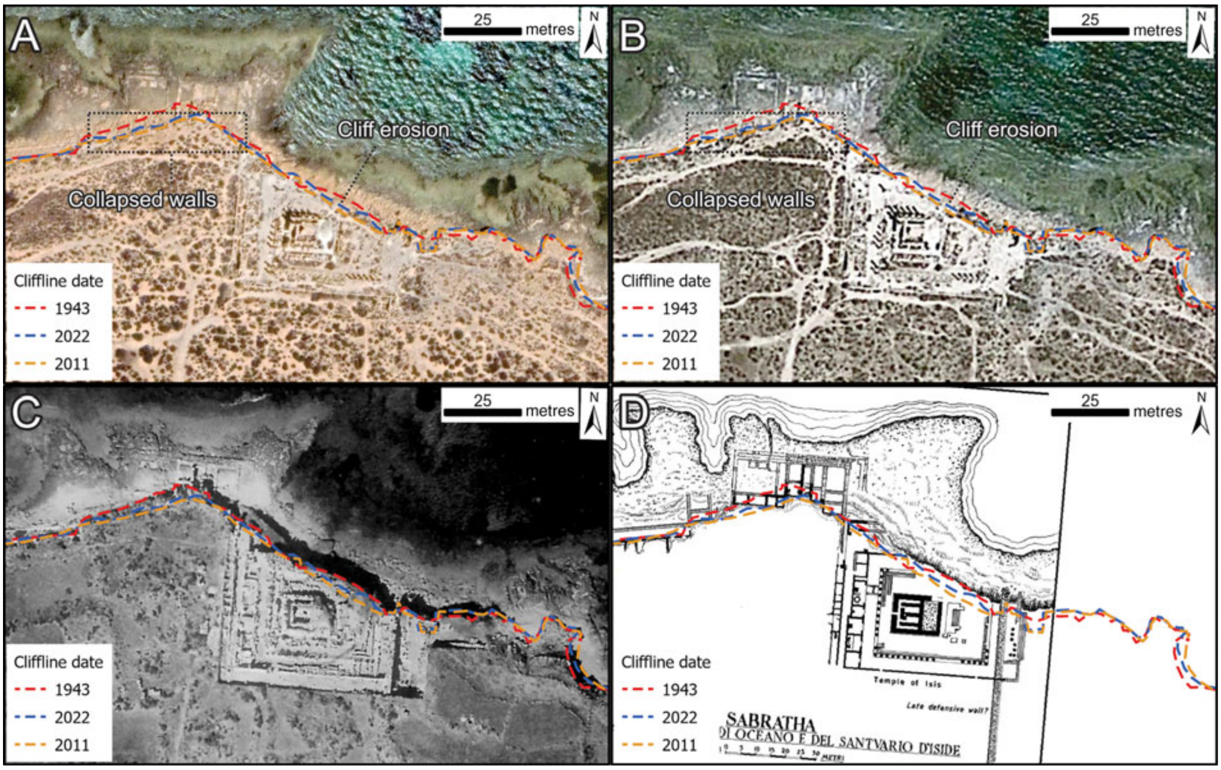

Figure 12. Area around the Temple of Isis at the Sabratha WHS at different time periods. A) 2022 GE VHR image; B) 2011 GE VHR image; C) 1943 aerial image (from BILNAS archive); D) site plan created in 1951 (from Kenrick 1986: Figure 125). Digitised shoreline proxies (vegetated cliff/backshore edge) are superimposed as coloured lines (see online colour version for a clearer reading).

Summary

The pattern of change at Sabratha comprises a period of coastal erosion some time during the second half of the mid-twentieth century followed by a period of apparent stability within the last decade. Even with this overall pattern, some areas are subject to more erosion than other areas. The precise reasons remain to be confirmed and would require more detailed study of local wind-wave regimes, coastal geomorphology and geology and, ideally, additional high-resolution imagery which can fill the gap between the 1943 and 2011 images used here. Nevertheless, some hypotheses can be suggested. First, that the coastline here experiences a trend of generally slow erosion. Thus, major changes are only visible over longer timescales such as the ca. 70-year period leading up to 2011 versus the decade bracketed by the 2011 and 2022 images. However, this cannot be confirmed without data from within the 1943–2011 interval, which would help to show whether the trend has been indeed progressive or proceeded in shorter, but more rapid, pulses of retreat. On the other hand, the fact that some areas – such as the bay between Church 4 and the Oceanus Bath (Figure 9) – formerly experienced rates of erosion sufficiently high to be visible on a decade timescale but which are now stable argues against this hypothesis. A second possibility is that rapid erosion has genuinely been stopped or considerably slowed. For the Seaward Bath headland this could be because of the recently built seawall. However, the stretch from the Seaward Bath headland east to the Oceanus Bath lacks artificial protection. It could be that for this area, vulnerable unconsolidated sediment within reach of the waves has now largely been removed, exposing the underlying (less erodible) bedrock. Effectively, a natural limit has been reached on erosion under present-day conditions. This is supported by comparison between 1943 and recent imagery, the former of which shows a more extensive beach fronting the aforementioned stretch whilst the latter shows geomorphology suggestive of bedrock cliffs and platforms. The trigger for the original erosion is not known. The site plans and 1943 photos suggest that it had occurred prior to then (exemplified by the Temple of Isis and foreshore structures), but the rapid, late-twentieth century coastal retreat would also fit with observations elsewhere in North Africa where the drivers appear to be anthropogenic: namely urbanisation, upstream damming and coastal sand-mining (Hzami *et al.* 2021).

If the most recent shoreline change rates are maintained, the Sabratha WHS generally will see relatively little change in the next decade except for structures close to the water's edge or within the zone of wave attack, especially during storms. This does not rule out the possibility of more extensive but localised changes, caused for example by cliff collapses during particularly large storms. However, the level of threat will increase as twenty-first-century sea-level rise (SLR) increases the frequency of major flooding events and pushes the zone of wave attack up and inland. This fits with the pattern of impact modelled by Vousdoukas *et al.* (2022) for Sabratha in that the main impacts come post-2050 as a result of accelerated SLR: 0% of the site is projected to be exposed to flooding and erosion by 2050 under both medium and high greenhouse gas (GHG) emission scenarios, increasing to 3.8% and 7.7% under medium and high GHG scenarios, respectively.

Discussion

Maritime archaeology is a slowly growing field in North Africa and the professional capacity which allows the documentation and management of coastal and marine cultural heritage remains relatively low. There are multiple reasons for this, not least the limited funds available to local antiquity authorities (which also contributes to lack of maintenance and neglect), the marginalisation of heritage in coastal/marine management, as well as in general development practice, and often a lack of awareness of the nature, extent and significance of maritime cultural heritage (Blue and Breen 2019). Legislative issues may also play a part. Suakin has shown how legislative complexities can create problems, while elsewhere the suspension of legislation during and post-conflict (e.g., Libya) can leave heritage extremely vulnerable. Even in more stable countries across the MENA region, loopholes or weak legislation encourages development at the cost of the existing cultural heritage.

Low in-country capacity and limited academic interest in the North African coast has also resulted in relatively few comprehensive and detailed maritime studies of North African harbours. Even some of the more prominent sites remain understudied, including the harbour facilities at the WHS of Sabratha that were recorded in the 1960s (Dallas and Yorke 1968; Yorke 1966; 1986) but have barely been fully and systematically investigated and published since (see, e.g., D'Urso *et al.* 2015 for a brief account on their bathymetry survey at Sabratha). In Sudan, underwater investigation has taken place at Suakin, albeit on a very small scale, but the ancient harbours of Badi and Aydabh remain largely unexplored (see e.g., Adam 2017; Kawatoko 1993). Furthermore, smaller sites and features, such as minor harbour settlements/anchorages, industrial features and farms, as well as sites that are not of the classical period, have received relatively little attention and remain poorly understood, even though they would greatly enhance our understanding of how maritime connectivity, trade, economies and maritime communities functioned on a local and 'global' level over time (Hesein 2015; Nikolaus *et al.* 2022; Schörle and Leitch 2012; Slim *et al.* 2004; Stone 2014; Wilson *et al.* 2013; Yorke 1972). Across the MENA region, these smaller sites often fall victim to urban and industrial development with no or little pre-development mitigation, but even large, better-known and historically important sites are also not necessarily safe from such threats, as demonstrated here in the case of Suakin.

The case study of Sabratha served to highlight another major threat to archaeological sites across the MENA region, that of coastal erosion. Archaeological sites affected by erosion can witness the exposure of previously undocumented material, damage to or collapse of standing structures and, at worse, rapid destruction over short timescales which ultimately leads to the irretrievable loss of valuable information (Gregory *et al.* 2022). Although coastal erosion is often linked with climate change, it is a natural process which can be (and often is) exacerbated by human actions that disrupt natural patterns of sediment supply, for instance via beach sand-mining, hard coastal defences and upstream damming. All of these have occurred along the North African coast as a result of intense twentieth-century development and urbanisation, with the end result being accelerated erosion in many places (Hzami *et al.* 2021). That said, there is a strong likelihood that coastal erosion will increase over the coming century, especially post-2050, with rising sea levels caused by climate change and, in some cases, accompanying changes in storm frequency and intensity (IPCC 2019; Vousdoukas *et al.* 2020; 2022). Shoreline change assessments, such as at Sabratha, can highlight particularly vulnerable sections of the coast, and thus provide heritage managers and archaeologists with essential information to enable them to start to tackle the problems that are ongoing. These studies can also contribute to a better understanding of coastal processes, which are often quite variable on local to regional scales, and therefore can aid identification of problems that will arise in the future. The above applies not just to areas with known or documented archaeological material. Some of the most vulnerable locations are those where deposits of unconsolidated sediment conceal or bury unrecorded archaeological material but lie close to the water's edge. It is, therefore, crucial to investigate those areas of an archaeological site that are still 'blank spots' on our maps before they are washed away by the sea. Not only does the kind of work presented in this paper raise awareness to the issue across the MENA region, but it can also inform the prioritisation of resources that may help protect vulnerable sites or portions of sites in the future.

Conclusion

The primary aim of the MarEA project is to systematically map and document maritime cultural heritage across the MENA region, with a particular emphasis on threat and damage assessment. The two case studies presented in this paper exemplify the type of work MarEA has conducted in North Africa to date. Together they highlight some of the main threats and damages which archaeological sites face across the region, namely urban development, lack of maintenance and coastal erosion. Importantly, the data gathered by the remote sensing assessments – as exemplified in the Suakin case study – are available through the EAMENA open access online database (database.eamena.org) thus providing a baseline assessment of the nature and condition of the heritage resource, that is readily available to heritage professionals and researchers. The available information can be used to identify sites within a given region which are most vulnerable to a particular threat/range of threats and thereby prioritise these for further action: for instance, more in-depth documentation/study before further loss and damage occurs or more regular monitoring to keep track of site condition. Newly acquired information can also be added to the EAMENA database to enhance existing records, which ensures that the baseline assessment remains up to date. The comprehensive and systematic documentation of the cairns and tombs at the eastern foothills of the Red Sea Hills in Sudan, exemplified in the Suakin case study above, shows how this type of work can also support and expand existing research in a sustainable, low-cost manner, via the geospatial and digital documentation of un- or minimally documented features (Andreou *et al.* 2022b).

The case study of Sabratha highlights another important component of MarEA's work – shoreline change analysis extracted from satellite imagery to explore ongoing and future impacts of coastal erosion on archaeological sites. Coastal erosion is not a new phenomenon but has been happening along the Libyan coast for centuries. What is alarming is that the analysis suggests an acceleration of this natural phenomenon in recent years. This is not only the case at Sabratha, as exemplified in this article, but is happening along the Libyan and North African coast (Vousdoukas *et al.* 2022; Westley *et al.* 2021; Westley *et al.* 2023). It is, therefore, of high importance to identify particularly vulnerable sites and to study in detail the impact coastal erosion might have on them. This allows for targeted and detailed documentation and the development of protection strategies before elements of these sites are lost to the sea forever.

Acknowledgements. We are grateful to Arcadia, a Charitable Fund of Lisbet Rausing and Peter Baldwin, for generously funding our project. We would like to thank the EAMENA team (Oxford, Durham and Leicester Universities) for their collaboration, and acknowledge support from antiquities departments, archaeologists and scholars from the MENA region.

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