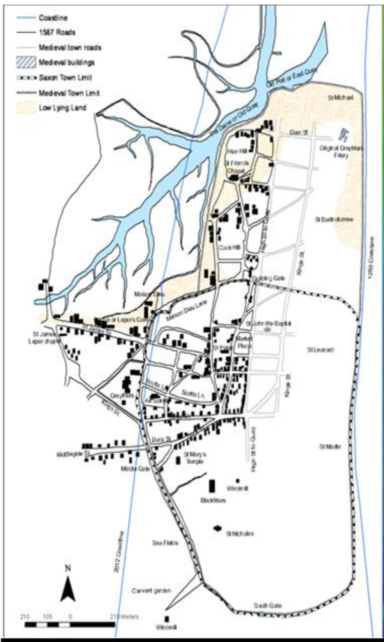
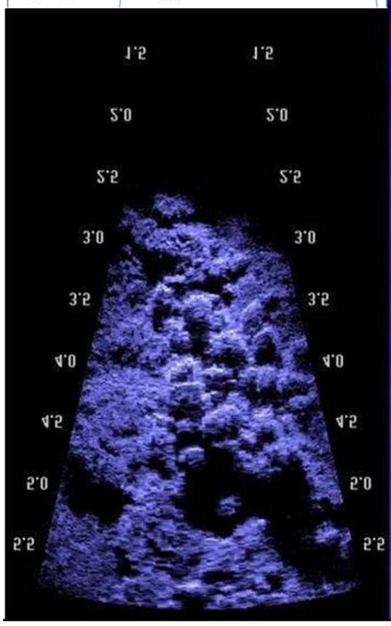
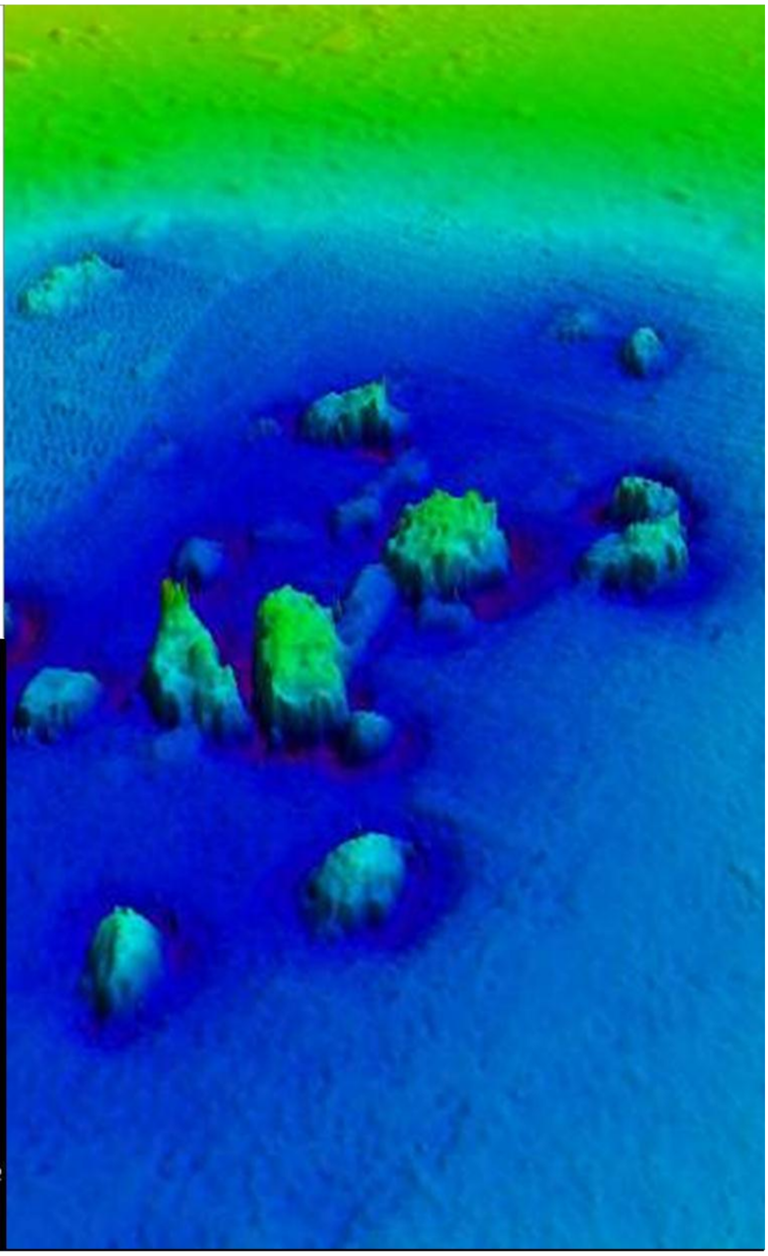
Dunwich Project 5883
Final Report







David Sear, Andy Murdock, Tim LeBas, Paul Baggaley, Gemma Gubbins.

FINAL REPORT

Title: 5883 Dunwich, Suffolk:Mapping and assessing the inundated medieval town.

Author(s): David Sear (UoS), Andy Murdock (GDI), Tim LeBas (NOC), Paul Baggaley (WA),Gemma Gubbins (GDI).

Derivation: 1^{st} Draft Project Report.

Origination Date: 5^{th} October 2011

Reviser(s): Unspecified

Date of last revision: 9^{th} March 2013

Version: 1.3

Status: FINAL

Summary of Changes: Final report. Includes modifications specified by reviewers on first progress report and draft final report.

Circulation: Project Officer Helen Keeley

Required Action: Confirmation of receipt by PO.

File Name/Location:

Approval:  David Sear Project Executive

Executive Summary

Project 5883 Dunwich, Suffolk: Mapping and assessing the inundated medieval town has delivered and exceeded all of the objectives and produced all the outputs as specified in the Project Design (See Table (i)).

In summary the project has:

1) Compiled and digitally captured all available maps, charts and pilot books for the section of coastline at Dunwich. These have been screened and evaluated in terms of their accuracy and information content. These were used to reconstruct the limits of the town, and to determine the position of the historic coastline at different times back to 1587.
2) Applied Coastal Change Analysis (CCA) and Bathymetric Change Analysis (BCA) to a) forecast the position of the coastline in 2050 and 2100, b) hind cast the coastline back to 1000 A.D., and c) determined the synoptic and local changes in coastal morphology around the Dunwich town site.
3) Undertaken geophysical survey of the northern harbour area of the town together with detailed survey of the existing major ruins on the seabed. This included magnetometer, Sidescan sonar, Multibeam and DIDSON acoustic imaging. Constraints at the time of survey restricted DIDSON survey to one of the two sites specified in the Project Design.
4) Collated all existing land-based archaeological data and integrated this with the CCA forecasts of cliff position to determine the heritage at risk to coastal retreat. This has identified between 6-14 sites at risk between 2012 – 2080. A list of recommended future work at the site has been compiled on this basis.
5) Collated all available marine geophysical and diver survey data and used this to identify the extent and type of marine archaeology over the town site. This data has been integrated with BCA to identify risks to marine heritage. A list of recommended future marine archaeology survey at the site has been compiled on this basis.
6) Reconstructed the topography and geography of the medieval town as the basis for defining the boundaries of the site that are expected to contain most of the archaeological heritage on land and in the marine environment. Although the boundaries are contestable, they provide a basis for any future consideration for heritage protection of the site.
7) Evaluated the use of DIDSON acoustic imaging sonar for use on the Dunwich town site. We compared both quantitative and qualitative outputs from all geophysical survey techniques. The DIDSON system provides additional valuable qualitative data on the environment and archaeology of a site, and can provide quantitative data that is statistically similar to Sidescan and Multibeam data.

ACKNOWLEDGEMENTS

The authors wish to thank English Heritage for their support and for funding this research and in particular; Ian Oxley, Peter Murphy, Mark Dunkley and John Etté who have consistently supported the project. A special thanks too for Helen Keeley the Project Officer for all her wisdom at crucial times.

The authors wish to acknowledge the assistance of the following people who helped us obtain and understand the historical documents used within this research.

First and foremost, the people of Dunwich and the Dunwich Museum Trust, who have supported this and earlier projects with great enthusiasm. Also, to Andy Rose, Duncan Coles and the LearnScuba divers. For his continued enthusiasm and help with the DIDSON we thank Mike Sawkins of McArtney AS.

Brian Thynne and Emma Lefley of the National Maritime Museum offered useful insight into their collections and facilitated supply of imagery. Guy Hannaford and Matt Millard of the United Kingdom Hydrographic Office Archives provided a good deal of useful information on historical charts and pilot books available for this period. We are also grateful to Katharine Chant and Giles de Bertodano of the Dunwich Museum for information and mapping from the Downing College Library, and Dunwich Museum research collection. We want to thank the staff of Maritime Museum Rotterdam, Netherlands and Christopher Jones UKHO Tides Team for help with standardising chart Datum for bathymetric change analysis.

We wish to thank Jenny Wraight (Admiralty Archive, Portsmouth) who retrieved a wealth of material including charts and sea atlases and to the Jenny Ruthven, Karen Robson, Sarah Harder, A Begley, A Pavule and A Hassan of University of Southampton Library – Rare Books Section for copies of the Coasting Pilot.

We are grateful to John Gator and the Time Team for access to their geophysical data, and to Wessex Archaeology for provision of the Archaeological report for the Time Team Dunwich dig.

We are also very grateful to Katherine Bryson and Lindsay Jones of the National Monuments Record, Swindon who facilitated supply of historical aerial photography used in the coastal change analysis.

Finally we also wish to make a special mention to Stuart Bacon of Suffolk Underwater Studies, whose pioneering work provided the inspiration for the research in Dunwich, and who provided access to original maps of the archaeology of the site found during his many dark and cold dives.

CONTENTS

List of Figures

List of Tables

Introduction

1 AIM AND OBJECTIVES

1.1 PROJECT AIM

The project aim is to provide EH with georeferenced digital historical (cartographic) data, high resolution geophysical data and interpretations to allow further, decision-orientated progress towards designation of the Dunwich town site. The project also aims to advance EH technical understanding of rapid non-wreck site evaluation through the design and application of an integrated survey methodology.

1.2 PROJECT OBJECTIVES

The objectives of this study are as follows:

O1 To collate, digitize and interpret existing secondary data to refine the definition of the form and extent of the medieval Dunwich site.

O2 To better define the northern and eastward extent of the former town and the location and form of any existing archaeological structures visible above the seafloor.

O3 To assess the heritage and archaeological value of existing structures identified on the sea floor through novel deployment of high resolution MBES and DIDSON DH technology at the St Nicholas Church and St Katherine's Chapel sites.

O4 To advance EH technical understanding of rapid non-wreck site evaluation through the design and application of an integrated survey methodology.

O5 To use the historical data (O1) to formulate estimates of coastal recession with which to estimate the risk to existing terrestrial heritage at the Dunwich site.

O6 To interpret and report the new information collected within the project as a basis for site designation and to make the results of the project available to specialist and general audiences, both in England and globally.

2.0 BACKGROUND

2.1 CONTEXT

2.1.1 Coastal recession has led to the loss of over 300 settlements around the southern north sea basin over the past 900 years (Sear et al., 2011). In many cases these were small hamlets or villages, but some were important international trading hubs and the centre's of regional prosperity.

2.1.2 The marine heritage value of these sites is poorly understood, despite their locations being relatively well documented. The heritage resource within the UK waters includes at least 215 medieval and an unknown number of Saxon and Roman settlements located along the eastern and southeast coastlines (Cracknell 2005).

2.1.3 These sites are important collectively as a long term record of coastal recession and as examples of archaeological sites subjected to differing modes of marine inundation that might form a model for the impacts of climate change on current coastal heritage.

2.1.4 Archaeological interest in these sites also lies in the preservation of information on structures and artefacts whose development was truncated by loss at a particular point in history (e.g. churches). Locally, these sites represent important sources of social and historical interest, providing a focus of community history and local interest.

2.1.5 To date, this heritage resource is poorly understood and investigated, not least due to the challenging environmental conditions at most sites, including poor to nil visibility, shallow water depths and burial (partial or complete) under silt and sand. Moreover, these sites are currently unprotected by any national or regional designation.

2.1.6 Given the extent of this resource and the comparative lack of understanding regarding its preservation and the information that can be derived from it, there is a need to develop approaches which can rapidly assess non-wreck sites for the purpose of designation and protection.

2.1.7 The medieval town site of Dunwich represents the largest and most important of the settlements lost to coastal recession within the North sea basin. It is unique in having a relatively well documented history back to the 13th century, and accurate cartography back to 1587.

2.1.8 In contrast to other marine heritage sites, it is large (c. 2km^2) and contains multiple concentrations of archaeological material and structures that provide information on the geography of the town that could be tied back to existing historical documentary records.

2.1.9 The main part of the town was lost in the 13th and 14th centuries and to date the precise extent of the pre-1587 town remains uncertain. Documentary evidence locates this early centre to the north and east of the site, on low lying land close to the former course of the Dunwich river. The area included 5 churches, one chapel and the remains of the internationally important harbour.

2.2 SITE SELECTION

2.2.1 The choice of Dunwich as an example site for non-wreck designation and protection is based on five factors;

2.2.2 1) The site represents an example of a major early medieval (and possibly Roman) settlement lost to coastal recession over a period spanning at least 1000 years. It is also representative of the other 215 coastal settlement sites in the UK (and in an international context, the 300+ sites around the southern north sea basin) that are known to have been lost to coastal recession over this period.

2.2.3 2) The site has extensive information already available on its historical development, significance, social as well as economic history and a local repository for this information in the Dunwich Museum.

2.2.4 3) The site of the town already has protection of three landward sites (Greyfriars friary (HER DUN092 and 094), Hospital of the Holy Trinity (OCN SF142), Chapel of St James (HER DUN005). The opportunity to seamlessly continue the designation and protection of the wider town site including the marine archaeology and submerged heritage is logical.

2.2.5 4) A large portion of the site has already been subject to cartographic, marine geophysical and diver based survey (Sear et al., 2009; in press). These have established the extent of the post-1587 site, the physical conditions over the submerged portion of the site and have confirmed the presence and condition of some archaeological remains where these protrude above the seafloor. In addition Greyfriars friary and the chapel of St James have both been the subject of recent archaeological survey (Boulter, S and Everett, L., 2009; Boulter 2008).

2.2.6 5) The landward sites are currently under threat from a range of pressures, most notably climate driven coastal recession and inundation. This includes the sedimentary sequences associated with the former harbour and estuary of the town and the site of the Hospital of the Holy Trinity. Seaward, coastal recession is driving the accumulation of silt and migration of sand banks over the site. This is rapidly reducing the exposure of archaeological material and limiting the detection possible using currently recommended geophysical technologies (e.g. Bates et al., 2007; Wessex Archaeology 2007). Thus the proposal is timely in providing an opportunity to quantify the detectable heritage as a baseline for designation and as an archive of the site.

2.3 PREVIOUS WORK

2.3.1 The project team has undertaken work on the Dunwich Town site in 2008 (EH Project 5546); 2009 (EH Project 5825) and most recently with the BBC in 2010.

2.3.2 English Heritage Project 5546 was partnership funded by the Esmée Fairbairn Foundation. The project collated, digitized and interpreted existing historical maps of the town and collected geophysical survey data over the central and southern part of the town site. This project provided the first accurate digital maps of the extent of the town back to 1587 AD as well as the first geophysical survey data of the town site.

2.3.3 Project 5546 trialled the application of Boomer sub-bottom imaging of archaeological materials. This confirmed that Boomer technology was not appropriate for imaging masonry structures buried under sands at the site.

2.3.4 Project 5546 identified four ruins on the seafloor, that diver surveys subsequently confirmed as the remains of medieval stone buildings. Comparison with the digital maps identified two of these as the ruins of St Nicholas and St Peter's churches.

2.3.5 Project 5546 involved Dr LeBas (National Oceanographic Centre) who provided technical input on geophysical data enhancement.

2.3.6 Project 5546 generated considerable public and scientific interest. Dissemination of the results have been global through internationally referenced publications (Sear et al., 2011), a new display in the Dunwich Museum, and a range of media outputs (www.dunwich.org.uk).

2.3.7 English Heritage Project 5825 was led by Wessex Archaeology and included Prof Sear as a technical advisor to the phase involving the Dunwich town site.

2.3.8 Project 5825 provided high resolution sidescan images of the four structures identified in Project 5546 as well as providing limited coverage of the northern area of the town. The latter confirmed the presence of morphology consistent with the presence of the former Dunwich river.

2.3.9 Project 5825 trialled the application of parametric sonar for sub-bottom imaging of archaeological materials. This successfully detected buried masonry associated with a medieval church site. The parametric sonar successfully imaged sub-bottom structures from the former course of the Dunwich river.

2.3.10 In 2009 and in July 2010 the BBC and MacArtney AS provided support for testing the application of DIDSON acoustic imaging camera technology at the Dunwich site. The trial confirmed that the DIDSON acoustic imaging camera can provide hi-resolution imaging of archaeological structures on the sea bed during zero visibility conditions. Resolution of the imaging was <10 cm and enabled identification of worked masonry, individual objects and larger rubble blocks.

2.3.11 Landward sites associated with the medieval town have been surveyed as part of site designation. These include Greyfriars friary (HER DUN092 and 094), Chapel of St James (HER DUN005) and the Hospital of the Holy Trinity (OCN SF142).

2.3.12 Greyfriars friary has been subject of a series of archaeological investigations including Norris (1936) who excavated a series of trenches around and to the NE of the existing ruins. Geophysical survey has provided evidence of extensive structures under the ground surface across the site (RCHM 1994). This was complemented by visual inspection and interpretation of the existing walls (Boulter & Everett, 2009). In June 2011, the site was the subject to additional archaeological investigation and Geophysical survey by Channel 4's Time Team (http://www.timeteamdigital.com/digs/the-coastal-site). This survey identified the former course of the Pales Dyke (town defensive ditch and bank)through the site, and confirmed the layout the Friary buildings to the north of the existing ruins.

2.3.13 The Chapel of St James (HER DUN005) has been the subject of recent visual inspection (Boulter, S. 2009), and lithic analysis (Palmer 2008).

2.3.14 The Hospital of the Holy Trinity (Site Of) (OCN SF142) has been the subject of rapid non-intrusive field evaluation as part of condition assessment for English Heritage in 1969; 1984; 1989, 1990 and most recently in 1991. In June 2011, the site was the subject to additional archaeological investigation and Geophysical survey by Channel 4's Time Team (http://www.timeteamdigital.com/digs/the-coastal-site). Geophysical survey failed to provide evidence of any buried structures in the Car park. Excavation of two trenches did turn up a cobbled surface, pottery and painted roof tiles, dating from the 13-14th Century. The results support the view that the main buildings of the Maison Dieu lie underneath the present Café site. The site report is under production with Wessex Archaeology.

2.3.15 Excavation of the Dunwich town defensive ditch (Pales Dyke) was undertaken in 1970 (West 1971) and in 1993-4; Reports on these exist. In June 2011, the site was the subject to additional archaeological investigation and Geophysical survey by Channel 4's Time Team (http://www.timeteamdigital.com/digs/the-coastal-site). A trench was dug across the line of the Pales Dyke within the perimeter wall of Greyfriars. This confirmed West's (1970) dimensions. Some fragments of early medieval/late Saxon(?) pottery were found at the base of this trench, providing some evidence for a Saxon origin to the defences.

2.3.16 Institute of Oceangraphy (IOS) surveys from 1970-1979 include oceanographic and geological data from the site; the latter providing stratigraphic information suitable for calibrating sub-bottom imaging data.

2.3.17 Good & Plouviez (2007) summarises the land based coastal heritage of the site and in particular the records and evidence for medieval and later drainage works within the former estuary of the Dunwich river, now the Dunwich and Dingle marshes. They also report areas of potential ridge and furrow identified from air photos to the north of Dunwich (DUN 036, 039, 046, 050), on land dipping into the drained marshes.

2.3.18 Substantial literature exists on Dunwich. These document the social, historical, political and economic development and structures of the town over the past c.1000 years.

2.3.19 The Dunwich Museum hosts data and artefacts from the town including material brought up by dives conducted at the site between 1970-1983.

2.3.20 Suffolk Underwater Studies in Orford hosts data and artefacts from the dives conducted at the site between 1970-1983. Stuart Bacon holds artefacts from his surveys in a private collection at his home.

2.3.21 A Heritage Lottery Grant awarded to the Dunwich Museum Trust ran until April 2012. This collated and digitized existing documentary material held by the Dunwich Musuem, Suffolk Country Records Office and some of the Dunwich related material held in the British Museum. This material is predominantly historical/social and is not map based, although maps for part of the archive. Access to this material is publically available via a searchable project website (www.dunwichmuseum.org.uk). The project produced 3 interpretation boards around the site focussed on the marine archaeology and coastal change. The project also included production of enhanced educational resources for KS3/4 that currently use Dunwich as a case study of coastal change. The project also hosted a 1 day workshop for knowledge exchange on coastal processes between stakeholders (Oct 2011).

2.3.22 This extensive information contributes to the Dunwich site being among the best documented non-wreck medieval maritime archaeological sites in Europe and the UK.

2.4 Historical background to Dunwich site

2.4.1 Most scholars agree that Dunwich was most probably the site of a Roman coastal fort, and was certainly a Saxon settlement (Comfort 1994; Bacon & Bacon 1979). Roman tiles are found in the ruins of Greyfriars monastery, the chapel at Minsmere and at Leiston Abbey. Divers from Suffolk Underwater Studies have tried to locate artefacts from the seabed to verify this theory, but so far without success (Bacon & Bacon 1979). The growth of Dunwich as an important town can be linked to the development of the marine fishing industry in the North Sea. Dunwich, along with other East coast settlements, was well placed to harvest the near-shore herring shoals, and was already an established site of Christian significance. The importance of the herring industry is reflected in the dedication of two of the early Dunwich churches, St Martins and St Michaels (Sear et al., 2011). The herring fishery was strongest in the 10^{th} and 11^{th} century, with declines during the 13^{th} century.

2.4.2 The precise size of the original town is unknown, but was sufficiently important to have once been the seat of the first Bishop of East Anglia, and to have received Royal Charters for a Market and a mint (Gardner 1754; Bacon & Bacon 1979, Chant, 1986). Prior to the Norman conquest, Dunwich is one of only four towns listed as having a market (Wade, 1999). In 1086 Dunwich was one of the ten largest towns in England (Comfort, 1994). The wealth of Dunwich was primarily based on sea trade, fishing and ship building; with substantial investment by different religious orders and at times, the crown.

2.4.3 Until the middle of the 14^{th} Century, Dunwich was a nationally important seaport. In 1225 it was approximately a mile from north to south, with an area similar to London's at that date (Gardner 1754). The town of Dunwich contained up to 18 ecclesiastical buildings (of which two remain Greyfriars monastery and St James - chapel to the Leper Hospital), a mint, a large guildhall and several large important houses (Comfort, 1994, Bacon & Bacon, 1979; Chant 1986). By 1242 Dunwich was the largest port in Suffolk, but this changed dramatically after the great storms of 1287 and especially 1328.

2.4.4 The population has been variously estimated at between 3000 and 5000 at its height, with at least 800 taxable houses, and an area of c.800 acres (Bailey, 1991; Comfort, 1994). Figure 1 summarizes the available data and documents the rise and fall of Dunwich as expressed in terms of the total population and the number of ecclesiastical buildings, itself a crude measure of wealth.

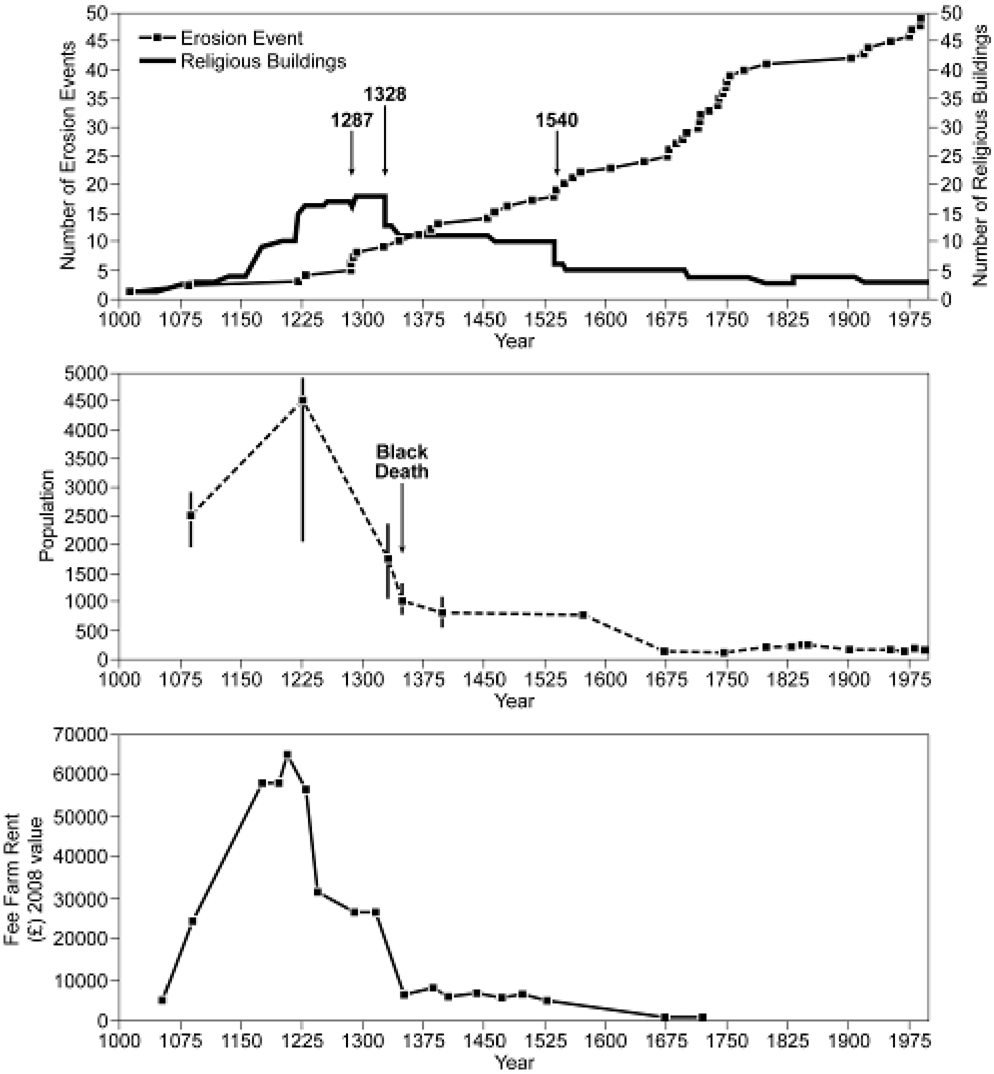


Figure 1 Development of Dunwich using three indices; Top, the number of religious buildings, Middle the estimated population and bottom, the Rental value paid to the crown. (Sear et al., 2011).

2.4.5 The demise of the city is as much related to the continual battles to preserve the open harbour as to the physical losses arising from coastal erosion. Loss of land at Dunwich is recorded as early as the Domesday book when over half the taxable farmland was lost to the sea between 1066 and 1086 (Gardnre 1754; Comfort 1994). Major losses were subsequently reported in the storms of 1287, 1328 and 1347, the latter resulting in the destruction of significant property (c.400 - 600 houses) particularly in the low lying portions of the city (Bacon & Bacon 1979; Comfort 1994; Gardner 1754; Bailey 1991; 1992). The minimum rentable values for the property lost in the storms of 1287-88 were £42. Following the storms of 1328, a further loss of equal magnitude resulted in a total of 375 out of 400 houses lost from the parishes of St Leonards, St Martins and St Bartholomew (Bailey 1991; Comfort 1994). Bailey (1991) makes the point that the indirect effects of coastal recession and sedimentation were often as significant as the physical damages themselves. Such costs included the repairs to infrastructure and the cost of rebuilding sea defences. At Dunwich this is exemplified by the sale in 1542, of church plate worth £2 to provide funds for building a pier to protect the Church of St John the Baptist from cliff recession (Gardner 1754; Bacon & Bacon 1979). Similarly, Galloway & Potts (2007) report that climatic deterioration, particularly the increasing frequency and severity of storms, made it increasingly difficult and uneconomic to defend the more vulnerable stretches of coast around the Thames estuary during the period 1250–1450.

2.4.6 The major losses of infrastructure and land at Dunwich during the period 1275-1350 coincided with a period of national economic crisis (Bailey 2007). Increased frequency of harbour maintenance and loss of income due to blockage and diversion of the harbour entrance to the north, would have hit a town economy already weakened by the national crisis. This is reflected in the collapse in market revenue in Dunwich during this period (Bailey 2007) and in the repeated pleas to the Crown for easements on the fee-farm rent (Bailey 1991). This period of climatically driven recession, was reinforced by the arrival of the plague in 1340, which reduced the population still further. An enquiry in 1326 highlights the abandonment of houses by their owners (and hence a reduction in rent income to the town) due to "obstruction and deterioration" of the port since 1278 (Bailey 1991). The economic decline in Dunwich continued into the 15th Century. During the first three decades (1400-1430), the fishing fleet slumped and income from the market stalls fell by 66% - in effect the town was now in financial crisis and continued to petition the crown for easements on taxation. The economic decline over the period c.1230 – 1402 is reflected in the collapse of the annual fee-farm tax to the crown, from £108 to £14. In c.1489, the status as a royal harbour for the Kings ships, was transferred to Southwold following further deterioration of the harbour at Dunwich.

2.4.7 The decline of Dunwich continued with the dissolution of the monasteries (1536-1545). Monastic houses in the town were already in decline, however, the loss of ready markets for fish and the direct loss of income generated by the monastic complexes of Greyfriars, Blackfriars, and the Templar church of St Marys, would at the least, have added to the sense of decline within the town. Additional physical losses occurred in 1560 and 1570 such that by 1602 the town was reduced to a quarter of its original size (Comfort 1994; Bacon 1982; Chant 1986). Further storms in 1740 flattened large areas of the remaining city, so that only All Saints church remained open, along with the ruins of St James' leper chapel, Maison Dieu hospital and Greyfriars friary (Gardner 1754; Bacon 1979; Comfort 1994).

2.4.8 The decline of the city was temporarily halted in the late 15th and early 16th Century which saw a resurgence in the fishing industry, notably the long range Icelandic fleet (Comfort 1994; Bailey 2007), but by 1785 the Icelandic fishing fleet in Dunwich was over.

2.4.9 The loss of All Saints has been well chronicled since it occurred during the late 19th and early 20th century, finally disappearing over the cliff edge in 1919. Fragments of All Saints were still exposed on the lower beach in the early 1970's. As of 2007, a final fragment and a single tombstone of All Saints Churchyard remains, and the south east corner of Greyfriars Monastery wall has been removed to prevent it from falling down the cliff.

2.4.10 The remains of the former medieval town now (2013) comprise the precinct, gateways and refectory of the Greyfriars monastery (Boulter & Everett 2009), the 12th Century Leper chapel of St James (Boutler 2008), the north west corner of the churchyard of All Saints Church, and a 150m section of the defensive earthwork around the western extent of the town, called the Pales Dike, including the former Bridge Gate (or 'Lepers Gate' CH 15.502 MS). The archaeological importance of the former estuary that form the Dingle and Dunwich marshes is unknown, but may well contain wooden structures and vessels associated with the former wharfage on the NW side of the town. Stratigraphically, the marsh sediments record a history of sea level change and storm deposition. Outwith these remains, and outside the boundary of the medieval town, the village of Dunwich includes properties that date back to the 18th century including the former Town hall, and School house, and buildings shown on the 1587 Agas map.

2.4.11 The site of Dunwich in relation to the southern North Sea basin is shown in Figure 2.0.

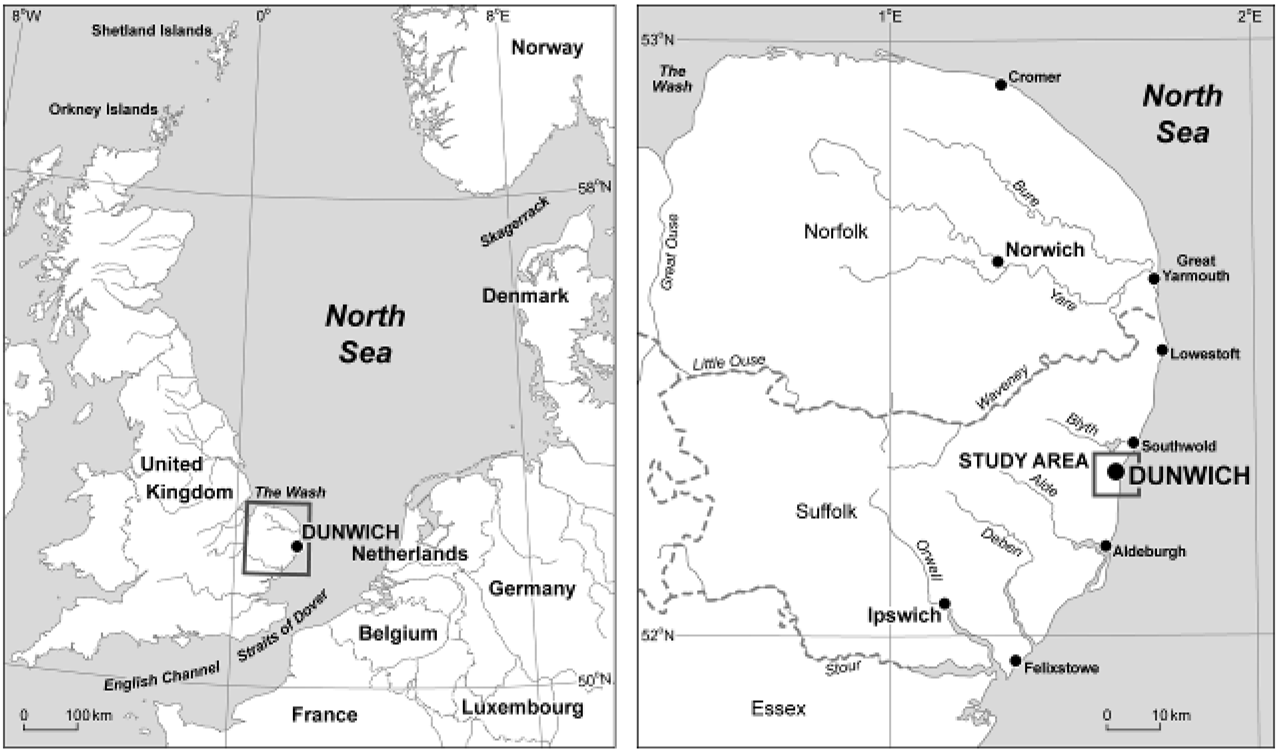


Figure 2 Location of Dunwich in relation to the North Sea basin (left) and to other main settlements on the Norfolk/Suffolk coast, (Sear et al., 2011).

3 METHODOLOGY (OBJECTIVE 4)

To advance EH technical understanding of rapid non-wreck site evaluation through the design and application of an integrated survey methodology.

3.1.1 Physical remains of non-wreck heritage in shallow littoral zones represents a major heritage resource, whose scale is becoming more apparent as a result of the Rapid Coastal Zone Assessment Surveys commissioned by English Heritage (for example, Good and Plouviez 2007). In many cases where these remains are exposed during low tides, they can be mapped and recorded using a combination of air photography and field visits. In other areas, visibility in the permanently submerged littoral areas is sufficiently good to combine geophysical surveys (Sidescan and Multibeam) with conventional diver surveys (WA 2003; 2004). However, for a significant length of the UK coastline, visibility is poor as a result of transport of fine sediment and phytoplankton productivity. Figure 3 shows how turbidity and suspended sediment concentrations are highest inshore, and associated with erodible soft rock lithology and sediment plumes from river estuaries.

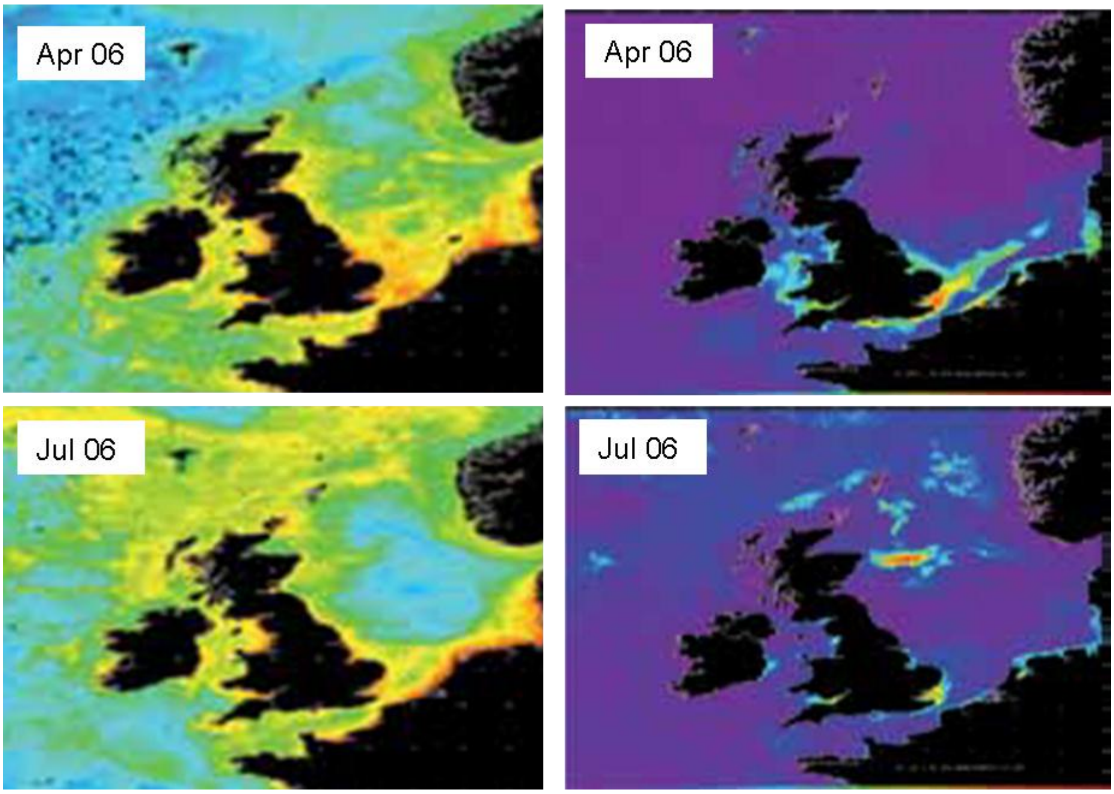


Figure 3 Maps of turbidity (left) and suspended sediment concentration (right) from satellite data. Warmer colours in both figures reflect higher values. These maps show the seasonal spatial distribution of suspended sediment during the periods typically used for diving in UK waters. Although showing data for 2006, the patterns are consistent between years. It can be seen that the Irish Sea, southern North Sea, and northern English Channel are subject to high sediment loads for most of the year except summer. This influences visibility. Images from Defra 2010).

3.1.2 The southern north sea coastlines of France, Belgium, Germany and Denmark are also subject to high turbidity and suspended sediment concentrations. Together with the eastern coastline of England, these contain over 300 recorded medieval settlements lost to coastal inundation and recession.

3.1.3 The Dunwich town site is a prime example of a largely unprotected, vulnerable (*sensu* Murphy et al., 2009) and valuable historic marine asset containing a suite of transitional archaeological contexts that, while typical of former coastal settlements, are perhaps more extensive than at other sites. These contexts include:

- waterlogged brackish and freshwater marshes.
- Transitional environments at the boundary of colluvial/alluvial depositional interface.
- Acidic sandy well drained sites.
- Moderate energy mixed beach.
- Moderate energy littoral environment.
- Littoral sandbanks.
- Urban contexts.

3.1.4 Moreover, the range of heritage is diverse, covering sedimentary archives (estuary environments), medieval structures and burials, a range of earthworks, a range of building structures and styles, a range of marine archaeological structures and artefacts and a range of documentary and data heritage associated with the site. This variety and wealth of information gives the site its heritage value. In addition the site is within an AONB, and has important landscape and conservation protection designations.

3.1.5 Finally, the site has a range of environmental conditions that define the type of investigations that are possible. These include, the presence of poor underwater visibility, the burial of marine heritage by offshore sandbanks and inshore mixed beaches, the presence of episodically eroding soft cliffs, the different mode of site destruction (cliff erosion, burial and re-exposure of foundations and structures by gravel barrier processes) and the presence of modern/existing buildings over earlier archaeology (notably the Maison Dieu site).

3.1.6 The approach required for the understanding and protection of the Dunwich site must take all these factors into account, whist evaluating the value and risk of the existing heritage.

3.1.7 The approach we adopted to collate and quantify the heritage at the Dunwich Town site was explicitly geographical; utilizing spatial mapping to integrate a variety of datasets that reflected the different environments and history of the site. Thus a key enabling technology was GIS (Figure 4).

3.1.8 Figure 4 summarises the overall project methodology. Nested within each sub-area are specific methodologies associated with each task. These are detailed separately within the rest of this report.

3.1.9 The Project has focussed on post Roman and largely post Saxon heritage at the Dunwich town site. It should be noted that earlier heritage is limited both in the number of records and their spatial extent; indeed many are simply reported as "discovered on the beach" (Good & Plouviez 2007).

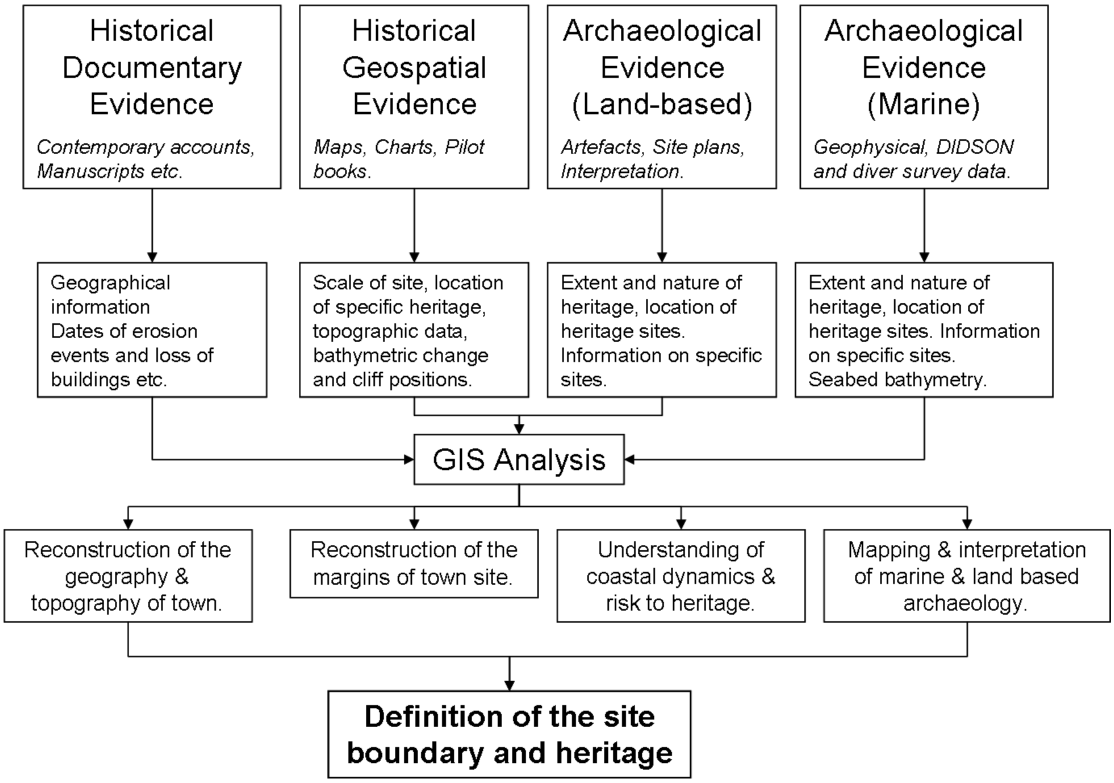


Figure 4 Methodological approach adopted within the Dunwich Town study, emphasizing the variety of data types and information. GIS provided the platform for collation and visualization of the data, leading to a definition of the heritage and extent of the town site.

4 HISTORICAL ANALYSIS METHODS AND DATA SOURCES (OBJECTIVE 1)

To collate, digitize and interpret existing secondary data to refine the definition of the form and extent of the medieval Dunwich site.

4.1.1 This aspect of the project sought to review a variety of resources not currently included in the existing Dunwich database (Sear et al, 2008). The aim was to fill gaps in both the spatial extents specifically for the area around the Dunwich River as well as gaps in temporal extents, especially the period between 1600-1800.

4.1.2 In addition, the datasets collated were also used to help estimate coastal erosion rates and bathymetric change in order to analyse the threat to the archaeology of the site but also to provide an indication of the potential recent accumulation of sediment over the submerged sites.

4.1.3 A variety of historical map resources for Dunwich have been reviewed (including charts, sea atlases and sailing directions, historical Ordnance Survey Mapping, artists paintings, war time aerial photos and photographs of the area of the town). This is potentially an open ended task that required a degree of elapsed time in order for data holders to evaluate and process the requests. The work also faced challenges due to the fact that some of the collections were held overseas, many had little information available online or were in the case of the some of the National Maritime Museum, currently inaccessible due to archiving of the collections.

4.1.4 Variation in the nature and extent of available metadata (information describing the map resources and their detail and content), meant that in some cases a significant amount of effort was expended in order just get to the stage of evaluating whether a resource would be fit for purpose in this context, as it was not possible to know how Dunwich was depicted until one saw the map. In some cases it was not possible to get to this stage, without incurring charges. In order to minimise the impact of this, we sought where possible to conduct extensive discussions with data providers before committing to purchases.

4.1.5 Unfortunately, few if any of the available map sources are as detailed as the map produced by Agas in 1587. In addition, the fact that by the time we get to our period of interest (1600-1800), Dunwich had already undergone significant decline, which meant that its importance was also diminished and was therefore, of less interest to cartographers. Therefore, it is mapped in less detail than some of the more significant ports close by (e.g. Yarmouth and Lowestoft).

4.1.6 Furthermore, the fact that the key sources for this period were maps and sailing directions within sea atlases, meant that the depiction of Dunwich on maps and perspective views, emphasise only those coastal features for the town which provided useful landmarks for navigation by sea and little if any detail of the inland extent of the town itself.

4.1.7 Despite this, a number of interesting resources have been identified which *do* offer new views of Dunwich during the period and which have not previously been incorporated into existing or published work on the town. These include coastal perspective views and descriptions which help support the timing of losses of churches to erosion.

4.1.8 In addition, it has been possible to collate a number of maps, charts and aerial photography and to extract coastline and sea bed (bathymetric) features from these for analysis within a GIS. This has enabled us to estimate rates of coastal change and changes in sea bed morphology and also to plot the changes to the town itself in terms of infrastructure.

4.2 HISTORIC MAPS AND NAUTICAL CHARTS – THE DATA SOURCES

4.2.1 Table 1 below is a summary of the major data resources and suppliers consulted. Often the same maps were identified by a number of different sources.

Name	**Description**	Visit made?
Dunwich museum map list	A list of map resources showing Dunwich, often with a low resolution thumbnail and /or link to the data provider. This resource with image links became available midway through the research period.	No –planned to coincide a visit with bathymetric survey but postponed until 2012
Robinson 'Marine Cartography in Britain'	Lists of charts available in several appendices – lists data locations, although some have now been moved to form part of other collections	N/A
UKHO chart lists and catalogues	Supplied by UKHO Archives	No
National Archives – online searches	Searchable list of potential resources	No
National Maritime Museum online search facility	Searchable list with zoomable map images available online. Not all the available charts are available to browse online.	No
Admiralty Library	Search provided by staff	Yes
Maritime Digitaal	Online search facility – not all holdings available on line	No
British Library	Initial searches only	No

Table 1: Principal Sources Consulted

4.2.2 Most of the charts were small scale maps covering long stretches of coastline, where the location of Dunwich was often indicated but not in any detail. In many cases these were included within sea –atlases (described below). As with the other nautical charts, the charts contained within the sea atlases are small scale maps covering long stretches of coastline. These books were designed to offer a single point of reference for sailors for the whole coast of the British Isles and often parts of the French and Dutch coasts too. Therefore, the detail for individual places like Dunwich is often coarse. Where more detailed charts were available, these tended to be insert maps focussing on the larger nearby ports, such as Harwich, Lowestoft and Yarmouth but stopped tantalisingly short of our area of interest (Figure 5).

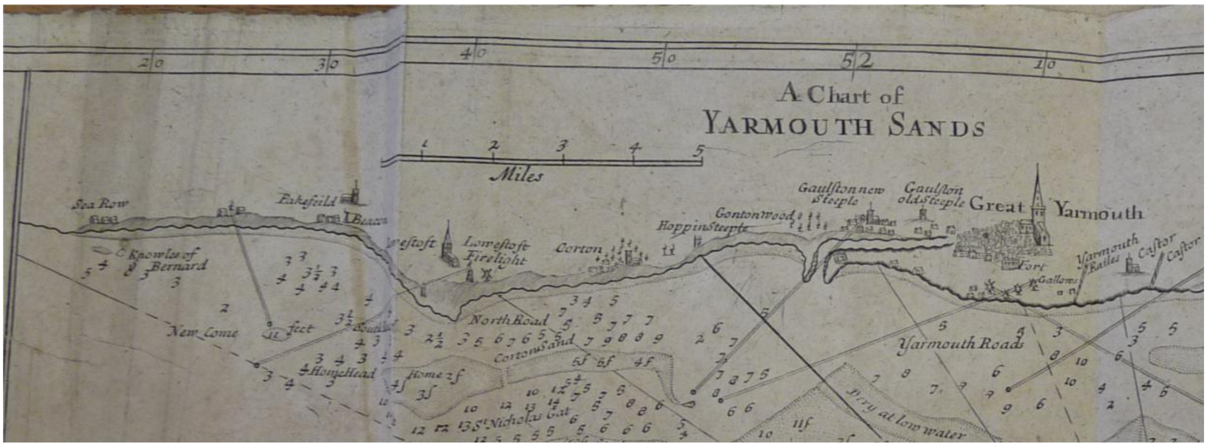


Figure 5 Chart of the entrance to Yarmouth Harbour, 1 of 3 more detailed insert maps showing the more important harbours along the Essex and Suffolk coast. Seller – English Pilot 1671, Admiralty Library copy.

4.2.3 In addition, where charts do occur they are often difficult to georeference accurately because they occur as folded (not flat) sheets and typically only contain rhumb[1] lines or have only the latitude marked, with the longitude scale either missing or with graduations based on a different meridian. This is because in some cases the charts predate the invention of Harrison's accurate marine chronometers (c.1761-1773) which made the reliable determination of longitude at sea possible.

4.2.4 Comparison with modern maps, also shows that the latitude is not always portrayed accurately on the graticule (map coordinate grid). For example, 53˚ occurs on the Mercator, 1595, map somewhat to the south of its true position which is slightly north of the North Norfolk coastline (rather than running through the eastern coastline of Norfolk). It is not clear whether this is down to error in the available survey instrumentation for measuring latitude or a 'post processing' error in the cartography.

4.2.5 While it would be possible with some effort to georeference these maps, it was not deemed worthwhile due to the small scale at which Dunwich is depicted. Despite this, the depictions of Dunwich *are* interesting as they typically show a church at the site and provide an appreciation of the gross morphology of the coastline in this location, often illustrating Sole Bay and the river inlets.

4.2.6 A series of examples are shown in the thumbnails shown in Table A1.1 (Appendix 1.0). This is by no means a complete list, with many more maps and charts described elsewhere (e.g. Dunwich Museum website). Therefore, these have not been duplicated here but are illustrative of the quality of information for the period. The Columne map is of interest, though because it shows 2 churches present at the site.

4.3 SEA ATLASES

4.3.1 The 'sea atlases' were some of the earliest references for sailors navigating along the coast and around Europe. They contained a mixture of charts (as described above), sailing directions describing safe courses to steer through, reference to coastal landmarks *en route* and some also showed perspective views of the coastline depicting land marks of use, such as towns, churches, windmills and beacons.

4.3.2 These sea atlases started to appear from around 1600 with the most notable cartographers publishing during this period being John Seller (circa 1630-1697) and Greenville Collins (c.1645-1694) who both published several editions of the *English Pilot* and *Coasting pilot of Great Britain* throughout our period of interest, often with the same or similar text occurring on subsequent editions. This continued after their

[1] A rhumb line is a line showing the shortest distance between 2 locations on a map and was traditionally used by sailors to navigate from A to B, by following a constant bearing.

deaths. The authors of sea atlases also often 'borrowed' from each other (Wraight, pers comm. 2011) and therefore, some of the charts and textual descriptions are identical. Elsewhere the perspective views or parts of charts are updated in subsequent editions of the same volume.

4.3.3 The findings from the review of these sea atlases are summarised below and focuses on the textual descriptions and perspective views contained within them.

4.4 SAILING DIRECTIONS

4.4.1 The sailing directions contained within the sea atlases provide descriptions of the coastline and instructions for courses to lay, in order to ensure safe passage around shoals, rocks and sand banks. In order to do this, the directions make reference to coastal landmarks, such as named towns, churches, windmills and beacons (and later light vessels) which can be used to aid navigation. The descriptions also refer to anchorages, bays, inlets and creeks which were potentially of great interest to the project in describing Southwold harbour and the course of the Dunwich river.

4.4.2 Table A1.2 (Appendix 1.0) summarises the textual evidence available for Dunwich. This includes some records post 1800, as these were easily available online. Notably again, the first entry Columne (1637) refers to the 2 flat steeples (ie church towers without spires as can be seen today at Walberswick Church that was built by the same person who built All Saints, Dunwich) at Dunwich, described on the map, all other references are to a single church. This suggests the timing of the loss of the tower of the other church (we presume to be St Peter's) to be sometime between 1637 and 1671. This corroborates Gardner's (1754) description of the Church being in ruins before loss to coastal erosion between 1688 – 1702, and the known closure of the Church in 1637 (Sear et al., 2008). Combining these contextual descriptions enables us to suggest that following closure, the tower of the Church collapsed at some point prior to 1671, with the site of the church and remaining ruins collapsing over the cliff at the end of the 18th Century. This confirms that the structural remains on the seabed are the remains of the ruins of the Church, rather than that of a complete structure.

4.4.3 The descriptions also give an indication of the significance of Southwold harbour ("a small creek") and the presence of the Dunwich river flowing into it from the south. Collin's description of 1781 (but based on surveys 1682-1689) talks of *"a bar haven, where at high water small vessels go in; there is good anchoring against these places from 8 to 12 fathoms".* His description also suggests that Dunwich was still accessible in some way by taking the southern of the three branches of the estuary, though the 1667 map does not show this extending as far as the town itself.

4.5 PERSPECTIVE VIEWS

4.5.1 The sea atlas descriptions are supported by perspective views which offer a sailor's eye view of the coastline through an artist's sketch (Table A1.3). Typically these are rather simplified and cartoonlike but depict the major landmarks, buildings, churches as well as aspects of coastal geomorphology. What they show is the elevation of the land at the coast and the position of large buildings.

4.5.2 The most interesting depictions are those of Columne in 1637 and Seller in 1671. These clearly show the location of two steeples, windmills to the south, and smaller buildings, all on the higher ground above the cliffs. These also provide clear evidence of a sloping area of land down to the position of the former harbour in the north of the town. The eroding cliffs are shown lighter than the other Areas of the coastline. This representation is confirmed by modern photographs of the coastline that show the light coloured eroding cliffs and the darker vegetated background and cliffs. Thus we can establish that the cliffs at these dates were active (i.e. not vegetated), corroborating the historical analysis of cliff retreat during this period (see later section).

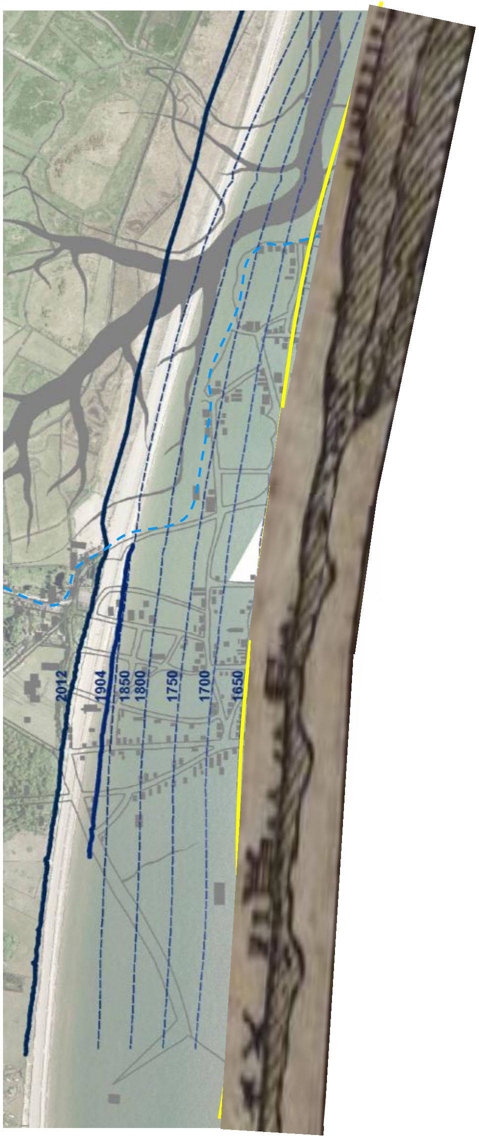


Figure 6 Perspective view of Columne (1637) stretched onto the 1587 map using landmarks consistent between the Agas 1587 map truncated at the appropriate dated cliff line. It is notable that there are a seriesof shallow valleys between higher ground suchas can be seen today. Also notable is the transition to lower lying land at the northern end of the town where it sloped down to the estuary. Yellow line is the cliff line in 1637.

4.5.3 The two earlier perspectives enable us to reconstruct the topography of the town and northern harbour area (Figure 6). By assuming the northern sloping area ends at the former exit of the Dunwich river, then it suggests that the central area of the town was on relatively high ground with an eroding cliffline of similar elevation. The pilot views of 1637 and 1671 both show houses on the lower lying area of the town towards the harbour. In addition to the towers of All Saints/ St Peter's church, additional buildings are shown to the north and south in both views. In Columne's 1637 view, two larger buildings are identified south of All Saints tower. Looking at the Agas map, it is possible that these are associated with the ruins of Blackfriars Friary, Greyfriars friary and the Temple. The two Windmills shown correspond to the two Windmills shown on the Agas 1587 map.

4.5.4 The cliff line is similar to the contemporary view, which shows eroding cliffs as a lighter face, backed by darker vegetated land rising behind. The cliffs in 1637 and 1671 extend all along the town, dipping down to Minsmere haven in the south, with three small valleys or low points. The position of the churches on the higher ground behind suggests that the land sloped seawards, hence the cliffs in 1637 and 1671 were somewhat lower in height that currently, although the precise difference is impossible to tell. An earlier coastal pilot view dating from c. 1586 (the time the data was collected for the 1580 publication) by the Dutchman Waghenaer, appears to show two low lying towers, with a third (All Saint's?) at a higher elevation behind. This would suggest that the land sloped down from the current cliff elevations.

4.5.5 From an archaeological perspective, these views confirm:

1. That the town sloped down towards the harbour in the north from a line approximately along the Maison Dieu lane.
2. That St Peter's church had a square tower as depicted by Agas, but that it had collapsed by 1671 – roughly the time Gardner records its proximity to the cliff line. It is known that the church was a ruin by this time (Gardner 1754).
3. The main area of the town was on higher ground that sloped seawards from a maximum elevation around All Saints.
4. Sear et al.'s (2008) suggestion that the St Katherine's chapel site lay on lower lying ground to the north of the site does not appear to correct, and instead is shown to be on the higher ground. This confirms that this building would have collapsed over a cliff.
5. Only land in the most northerly part of the town did not lie on higher ground and therefore was inundated rather than collapsed over a cliff. Hence the archaeology in this area is likely to be less disturbed.

4.6 HISTORIC ORDNANCE SURVEY MAPPING

4.6.1 In order to understand more recent coastal change historic Ordnance Survey mapping was analysed. This was available through EDINA DIGIMAP service for dates between 1849-1995 at scales 1:2,500 and 1:10,560 (County Series) mapping and 1:10,000 for National Grid for this location. Where available, the larger scale data was used.

4.6.2 The Top of Cliff feature was captured from these maps for the various epochs and forms one of the inputs to the subsequent DSAS analysis (Digital Shoreline Analysis System - USGS, 2008) . The shoreline polygon was also captured (Mean High Water line – as marked and the back of the beach, interpreted).

4.6.3 The inherent inaccuracies from historical maps have been widely documented (for example, Burrough and McDonnell 1998), and include projection, coordinate system and datum corrections, required for map series comparison, and personal interpretation when defining boundaries. (Taylor et al, 2004). There were no scientific assessments of the accuracy of OS large scale mapping prior to 1948 when the first National Grid maps were being published (Ordnance Survey, 2004). However, Taylor et al (2004) obtained accuracy values based on discussions with Landmark Information Group (who undertook the digital conversion) when they undertook an analysis of coastal steepening for England and Wales using historic OS data. Their quoted (absolute[2]) accuracy for the c.10,000 scale data was 3.5m post-1945 and 5m pre-1945. There is no information about the accuracy of the 1:2,500 data pre 1945, therefore, the 5m limit offers a conservative figure.

4.6.4 In addition the main infrastructure, roads, river and buildings were captured to show change over time, although this was only undertaken for a selection of the dates because some of the revisions did not offer significant change within the time series.

[2] Absolute accuracy refers to the accuracy of an object in relation to its true position on the ground. An absolute accuracy of 3.5m means that across the map, features are within 3.5m of their actual location on the ground. This is different to the relative accuracy which refers to a feature's position relative to other features on the map.

4.7 HISTORIC AERIAL PHOTOGRAPHY

4.7.1 A request was made to the National Monument Record (managed by English Heritage) for aerial photography which would provide additional timestamps for the analysis. The data ranges from 1940 to 1990s. The vast NMR aerial photography holdings are not currently available in digital format, nor is there an index map (available outside EH) depicting in detail the area covered by the various images. However, NMR staff kindly provided aerial photography footprint centres, along with other metadata and it was possible to filter the search down by plotting these within GIS and selecting the relevant centres, albeit with some uncertainty as to the exact footprint area.

4.7.2 The fact that these photographs are still mostly only available as hard copies, meant that the photographs had to scanned. We undertook this for 1940, and 1953, in order to provide data coverage for this period. Georectification produced errors that were larger than the change in cliff line and so these data were excluded from subsequent coastal change analysis.

4.8 HISTORIC PAINTINGS, PICTURES AND DESCRIPTIONS.

4.8.1 In addition to the coastal charts and maps, topographic and architectural information can be extracted from paintings, etchings and prints made of Dunwich by visiting artists and historians (McInnes 2010). Care has to be taken in the interpretation of artistic reproductions of landscapes which is exemplified by J.M.W.Turner's famous painting of Dunwich from 1830, in which the artist accentuated the dramatic qualities of the scene by rotating the church, increasing the height of the cliffs, and extending the area of ruins whilst removing any habitable dwellings and fishing huts (See Table A1.4). This form of data can be classified into that which provides information on, a) specific buildings in the town (e.g. All Saints Church); b) topography and relative positions of buildings; and c) details of the morphology of the beach and cliff line. Table A1.4 presents a sample of the available images; additional information is contained in the Dunwich Museum research database (http://www.dunwichmuseum.org.uk/research/index.php) and museum archives.

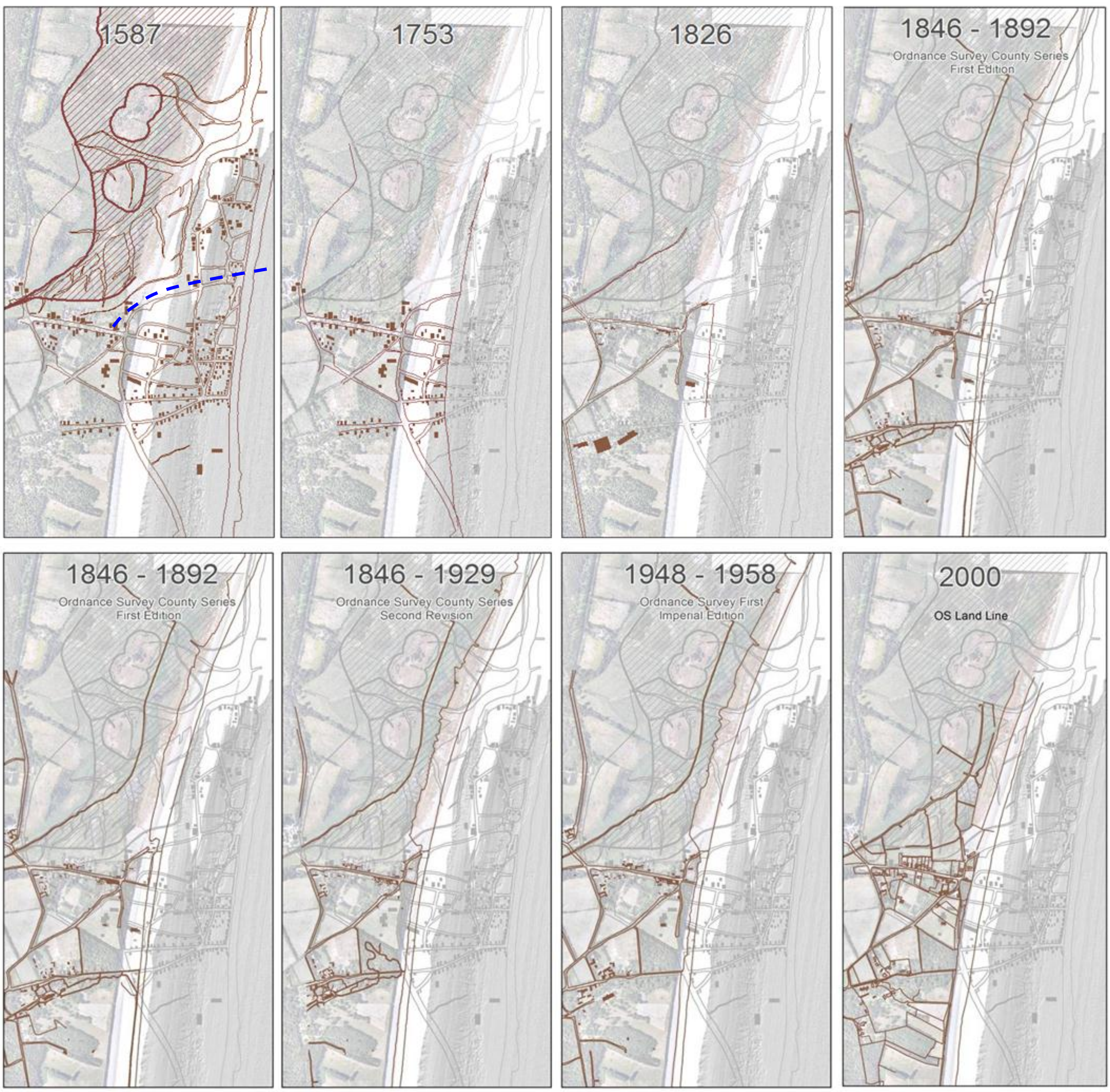
4.8.2 Of particular interest is the recent digital collection provided by the HLF funded grant to Dunwich Museum Trust. This includes the Fisk collection of photographs and drawings made around the turn of the 19th – 20th century. The photographs include information on the effects of the storms around the turn of the 19th century and specifically that of 1911. The photographs demonstrate the processes by which material from All Saints church were incorporated into the beach in large fragments, as well as providing information on beach levels. To the north of the existing village where the cliff level is lower, photographic evidence shows roads and building foundations in-situ on the beach following scour during the 1911 storm. This supports the hypothesis that at least initially; remains of structures of wood and stonework are exposed by scour and may be re-buried by the advancing shingle beach. Such an event was described by Gardener (1754) during the storm and flooding of 1740. He describes the complete erosion of Cock and Hen hills (formerly 40ft high) and the scouring of the land around them, revealing the foundations of St Francis chapel and the graves associated with it. He also describes structures associated with the old quay. Together these provide a model for the future of the Maison Dieu site, in which levelling of the gravel barrier and scour of the land surface during a large (or series of large) storm surges, reveals the buried structures and graves. It is at this point that a rapid "emergency" detailed mapping and recording will be necessary by the competent authority.

4.8.3 The images also show the continuity of cliff line and cliff morphology, with large storms removing the beach and steepening the cliff line, notably during the storm of 1911. Erosion rates during this period are known to be high, with the loss of All Saints 1903-1920. It appears that beach levels were recovering by 1913. This indicates that storms which remove the beach set up conditions for high rates of erosion, but that subsequent events can rebuild the beach quite quickly, through onshore sediment movement but also via mass failure of the cliff face resulting in sediment accumulation at the toe of the cliff (Brookes et al., 2012). The exposure of weaker material at the toe of the cliff is critical for cliff instability (Brookes and Spencer, 2010). However, Dunwich cliffs are reported to have Shelly crag at their toe (Royal Commission 1907) rather than clay as at rapidly eroding cliffs at Happisburgh and Covehithe. For the past century, a beach has remained at the toe of the cliffs, although its level has varied over time – for example in the 1970's blocks of the tower of All Saints were visible for a year.

4.9 CHANGES TO THE CITY OF DUNWICH IDENTIFIED FROM MAPPING

4.9.1 In order to show the changes to the city of Dunwich over time, the buildings and other features were captured as separate datasets from the available sources. These included Agas, (1587), Gardener (1753), Downing Estate Maps (1764, 1800), Tithe map (1826) and Ordnance Survey maps post 1846.

4.9.2 Plots are shown below with the current (2011) aerial photography and 2008 bathymetry as context (Figure 7).



1587
1753
1826
1846 - 1892
Ordnance Survey County Series
First Edition
1846 - 1892
Ordnance Survey County Series
First Edition
1846 - 1929
Ordnance Survey County Series
Second Revision
1948 - 1958
Ordnance Survey First
Imperial Edition
2000
OS Land Line

Figure 7 Changes to Dunwich Town derived from Historic and contemporary Mapping 1587-2000. (Hatched area is the estuary extent pre-1587 based on core sample depths and extraction of height contours (0.535m OD)). Blue dashed line marks cliffed area to the south and gravel spit/barrier to the north.

4.9.3 The sequences of coastal change in Figure 7 clearly show the decline in the town between 1587 and present. The most significant changes occurred between 1587 and 1826 when the majority of the remaining medieval town was lost, including the northern harbour area. The cliffed area south of the blue dashed line is not inundated or scoured compared to the gravel spit/barrier to the north. Larger important buildings were located on this higher ground and hence more have been preserved longer, culminating in the record of the decline in the church of All Saints, and the current Greyfriars ruins.

4.9.4 One of the more extensive areas of the former medieval landscape remaining are the sediments associated with the former estuary and harbour of the town. Evidence from the Time Team excavations at Maison Dieu, showed how the western edge of the lower lying area of the town backed on to the former estuary. Exploratory cores taken from the marshes, show estuarine clays pinching out into marginal saltmarsh/peats and sandy colluvium along the margins of the town site (Sear unpublished). Discussions during the 2010 Time Team excavations with Stuart Ainsworth (English Heritage) suggest that this margin may contain evidence of wharfs and maritime infrastructure. This area is therefore of important heritage value.

4.9.5 Figure 7 shows that many Tudor or earlier buildings were located west of the current (2012) coastline, and therefore represent an additional heritage resource. Lack of development over these buildings and their absence after 1753, points to preservation of early building styles and associated archaeology. West (1971) reports finding the remains of timber buildings with late 12th/early 13th century pottery just east of the Pales Dyke and the cliff. The site of the town and its suburban development extends west to Dearing bridge, with the Leper chapel and Leat hill representing the most westerly of the medieval remains at the site.

5 GEOPHYSICAL DATA COLLECTION 2012

5.1.1 Geophysical survey was undertaken late March 2012 following postponement due to poor sea conditions during the previously scheduled time in August/September 2011.

5.1.2 All datasets as stated in the Project Record were captured. One of the two days of DIDSON data capture was lost due to unsafe operating conditions that became apparent when attempting to deploy the equipment and diver. Consequently, data capture was only completed from one of the two planned sites (St Katherine's Chapel).

5.1.3 Wessex Archaeology (WA) was commissioned by the University of Southampton, to carry out geophysical survey work as part of the ongoing study of the submerged remains of the medieval town of Dunwich (Sear *et al.* 2009; Sear *et al.* 2011). This survey included acquiring sidescan sonar, magnetic and multibeam echo sounder datasets (MBES), with WA only being commissioned to process the magnetic data. The survey was focused on three areas just off the modern coast line. In addition to the area surveys, additional MBES work was carried out to locate the survey stations used as part of a separate Didson survey carried out by Mcartney and Learn Scuba.

5.2 AIMS AND OBJECTIVES

5.2.1 The aim of the survey was to acquire sidescan sonar and magnetic datasets to complement existing data including that which has previously been acquired in 2009 by Wessex Archaeology (WA, 2010). A multibeam echo sounder survey was also conducted with particular attention focused on the northern (harbour) area of the site and archaeological remains corresponding to the locations of St. Katherine's Chapel, St Peters and possible St Johns churches and St. Nicholas's Church and Blackfriars Friary further to the south (Sear et al., 2011).

5.3 GEOPHYSICAL DATA – TECHNICAL SPECIFICATIONS

5.3.1 The geophysical data were acquired by WA between the 27th March and 1st April 2012 on the survey vessel *Wessex Explorer*. The dataset consisted of sidescan sonar, multibeam bathymetry and marine magnetometer data.

5.3.2 The site was divided between three survey areas. The largest is the Northern survey area, covering an area of shallow water to the north of the recorded location of the Dunwich site. To the south of this there are smaller survey areas covering the recorded locations of St. Peter's Church and St. Nicholas's Church (Figure A2.1). In some cases the western most limits of the survey areas could not be surveyed due to health and safety concerns associated with working in shallow water.

5.3.3 A Klein 3900 system was used to acquire the sidescan sonar data. The system was operated at a range of 30m and a frequency of 900kHz.

Towfish positioning was provided by manual layback, with cable out measured and recorded for individual lines to be applied during processing. The data were recorded digitally using the Klein SonarPro software as *.xtf* files.

5.3.4 The magnetometer data were acquired using a Geometrics G-882 caesium vapour marine magnetometer. Towfish positioning was provided by the same manual layback method used for the sidescan sonar. The data were digitally recorded as. *GEOMAG* files using Geometrics MagLog software, and converted to .txt files using MagMap.

5.3.5 The multibeam bathymetry data were acquired by using an R2Sonic 2024 multibeam echo sounder system. The data were recorded digitally using QINsy.

5.3.6 For this survey all positions were recorded and expressed in WGS 1984, UTM Zone 31°N.

5.3.7 Figure 8 summarizes the extent of all available geophysical data captured in the vicinity of the Dunwich Town site.

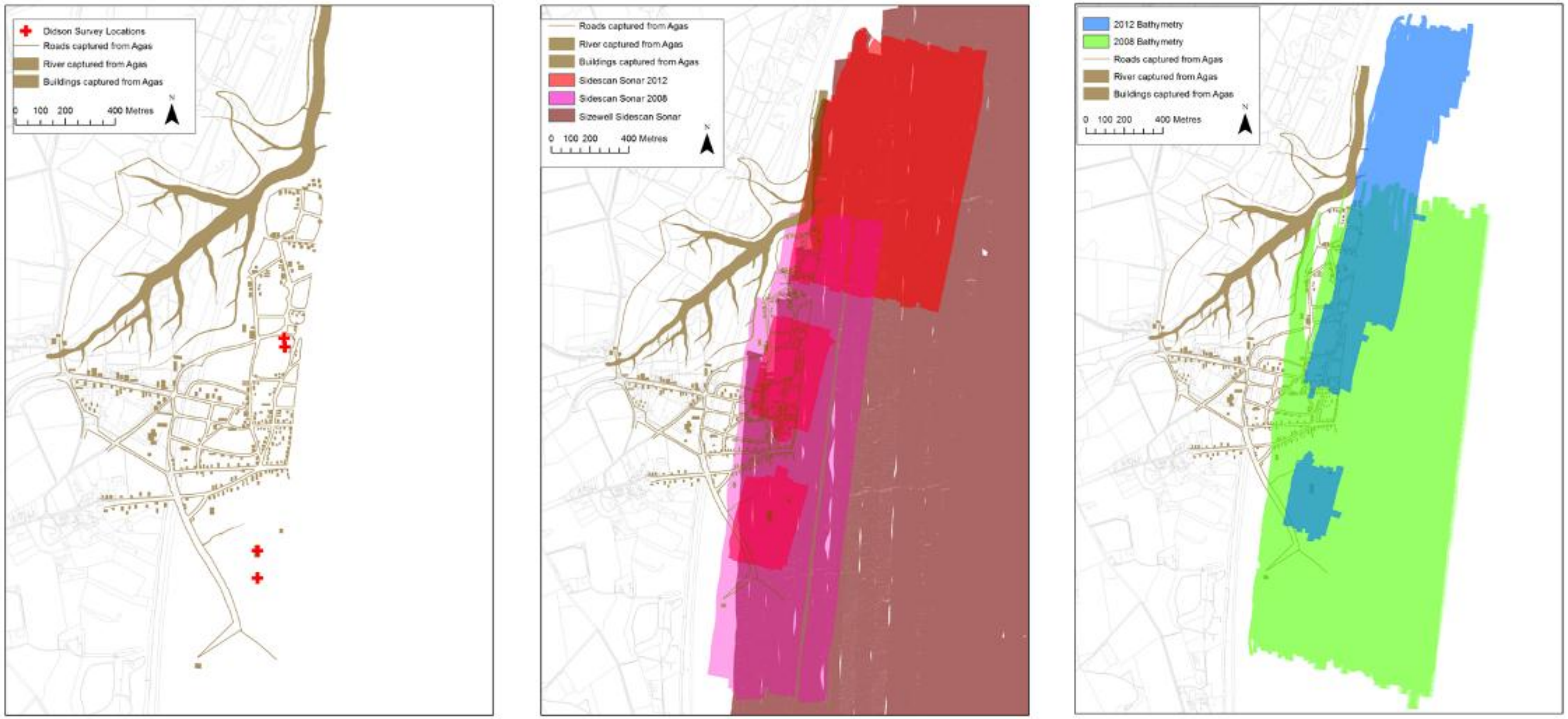


Figure 8 Survey areas for available geophysical data. Left; DIDSON acoustic imaging; Centre – Sidescan Sonar data, Right Multibeam data.

5.4 GEOPHYSICAL DATA-PROCESSING

5.4.1 The magnetometer data were processed by WA using Geometrics MagPick software in order to identify any discrete magnetic contacts which could represent buried metallic debris or structures such as wrecks. All anomalies identified have magnetic amplitudes above 5nT.

5.5 EMPIRICAL TIDAL CORRECTIONS & MBES PROCESSING

5.5.1 During the data processing for the multibeam bathymetry data it was apparent that using a measured tidal file from Lowestoft (even with correction to Southwold) did not have adequate accuracy for the resolution of this survey. It was therefore necessary to transform the tidal curve in small amounts of time and height to better approximate the tidal height for the Dunwich area. It is assumed that the basic shape of the tidal curve will persist.

5.5.2 Locations were chosen from the multibeam bathymetry data coverage where two depths were measured but at different times. In total 58 depth values were measured with varying time differences (Figure 9). These where fitted to the tidal curve using an iterative method. The final fitting changed day-by-day (Figure 10). The final fitting gave a standard deviation of 6cm for the fitted points whereas previously the standard deviation was 14cm. This does mean that absolute depth values have been altered and the datum is now arbitrary and thus the data should not be used navigation. However it does allow a bathymetric model to be created and thus facilitates interpretation.

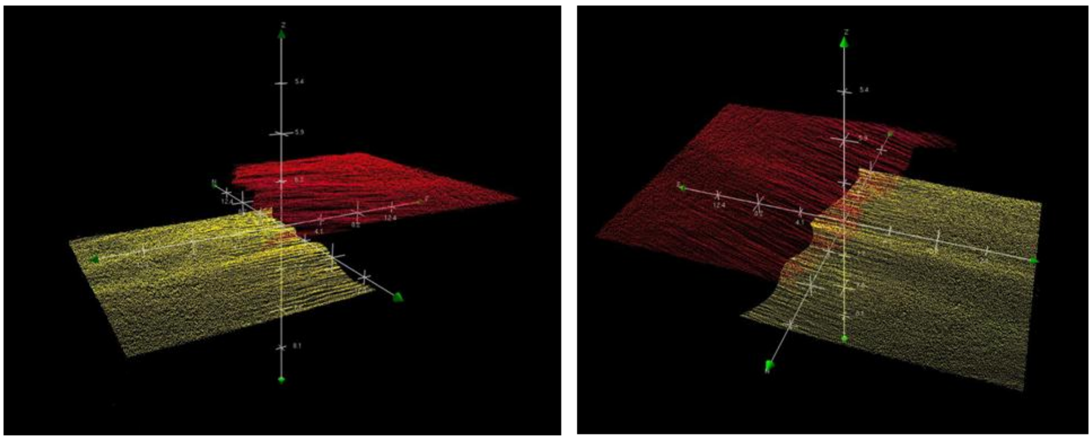


Figure 9 Examples of crossover surfaces used to define empirical tide corrections for the MBES datasets.

5.5.3 To match the tide curve, Day 1 (30/03/2012) and Day 2 (31/03/2012) were forward shifted in time by 15 minutes. Day 3 (01/04/2012) was backward shifted by 30 minutes. Day 2 was also positively shifted by 0.17m. Errors are generally less than 0.1m

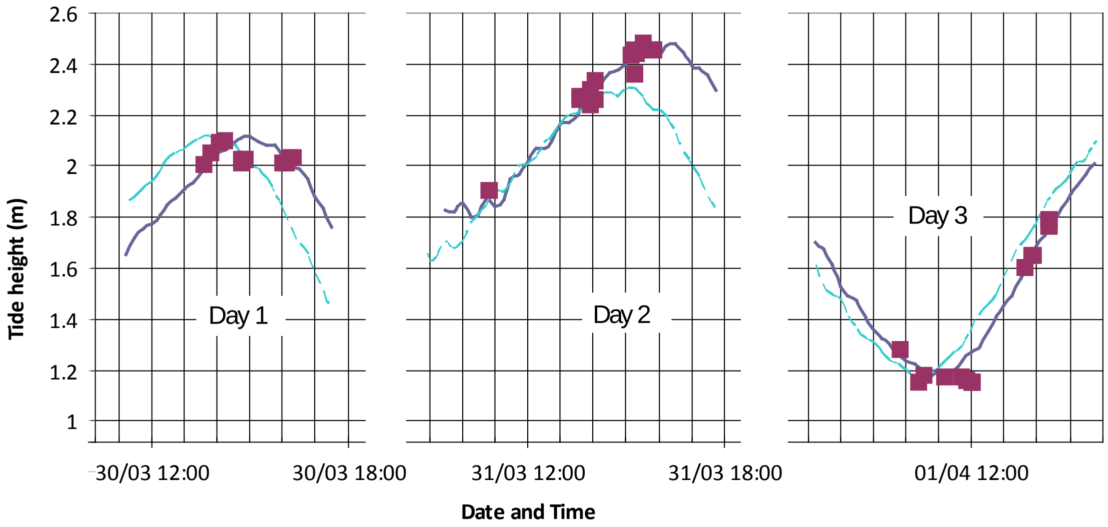
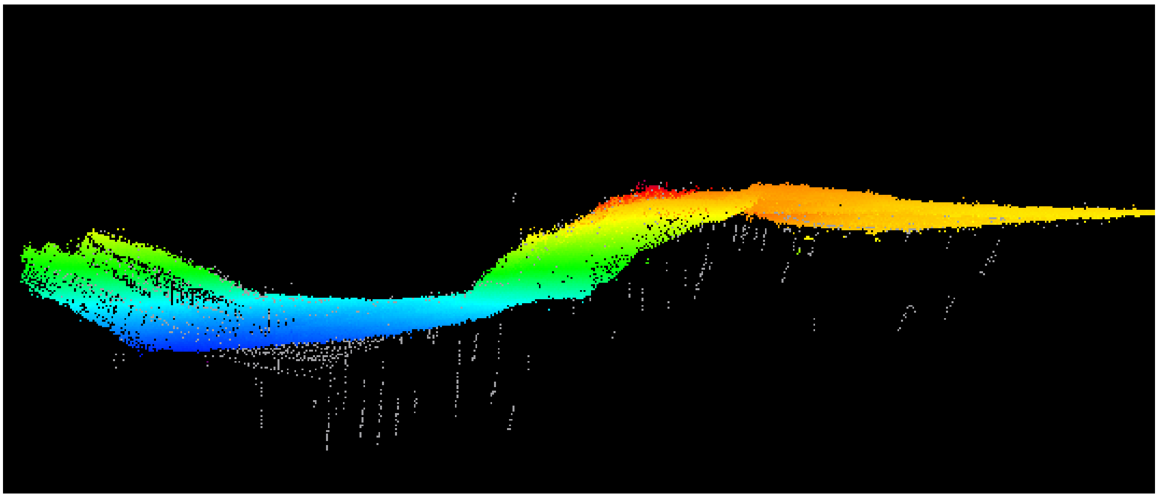
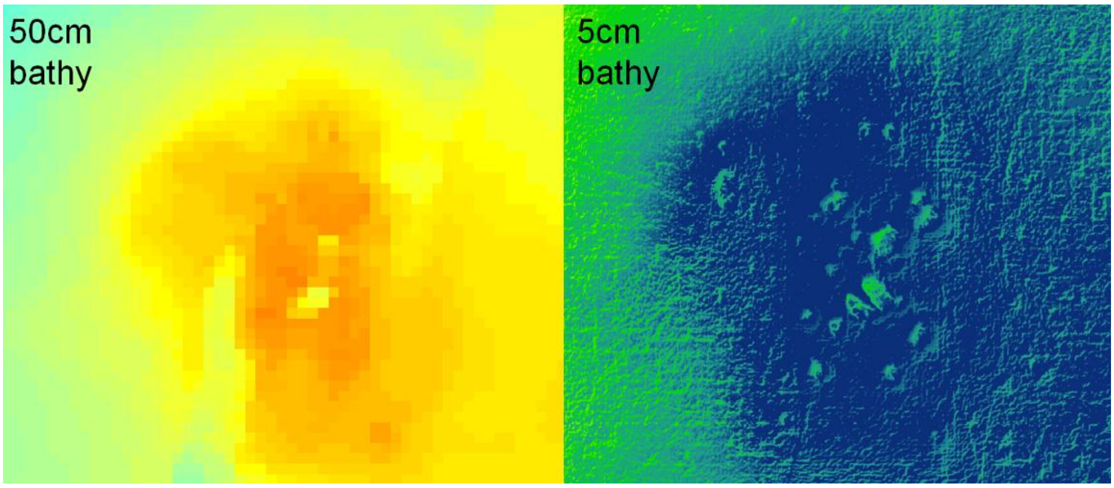


Figure 10 Tidal curve for Lowestoft for 3 days of survey (light blue curve), with best fit curve for Dunwich tide data (dark blue curve) and measured multibeam overlap points. An arbitrary depth (a datum was set) of 1.6m at 01/04/2012 13:41 to try to match the tidal curve.

5.5.4 The multibeam bathymetry was processed using CARIS HIPS v7.1. Sound velocity corrections were applied together with the tidal correction mentioned above. After geographic registration on a UTM Zone 31 (WGS84) 0.5 metre grid the data was viewed in colour relief. The subset editor was used to identify the points where obvious problem bathymetry data were seen, and the points were removed. Generally the data only had errors at far range, or occasional points were wildly in error. Figure 11a shows the rejected points in grey. The model can be rotated, tilted and zoomed in three dimensions and the offending points identified by a box or polygon. It shows all the soundings and not just the 50 centimetre grid which is created from the valid points using a search radius and weighting factor method integral to CARIS. The whole MBES data area was processed at 50cm resolution but for the main ruins this was increased to 5cm. The greater resolution enabled much better discrimination of features but did start to highlight the tidal differences of different swaths (Figure 11b).



a



b

Figure 11 a) Example of subset editor in CARIS HIPS. The model can be rotated in 3D and points picked. Grey points are bad data points edited out. Comparison of Multibeam Bathymetry Data at two resolutions for the St Katherine Site (colour scales are not calibrated).

5.6 MAGNETOMETER GEOPHYSICAL DATA – ANOMALY GROUPING AND DISCRIMINATION

5.6.1 The previous section describes the initial interpretation of all available geophysical data sets which were conducted independently of each other. This inevitably leads to the possibility of any one object being the cause of numerous anomalies in different data sets and apparently overstating the number of archaeological features in the study area.

5.6.2 To address this fact the anomalies were grouped together. This allows one ID number to be assigned to a single object for which there may be, for example, a UKHO record, a magnetic anomaly and multiple sidescan sonar anomalies.

5.6.3 2.3.3. Once all the geophysical anomalies had been grouped a discrimination flag is added to the record in order discriminate against those which are not thought to be of an archaeological interest. These flags were ascribed as detailed in Table 2.

Non-Archaeological	U1	Not of anthropogenic origin
	U2	Known non-archaeological feature
	U3	Non-archaeological hazard
Archaeological	A1	Anthropogenic origin of archaeological interest
	A2	Uncertain origin of possible archaeological interest
	A3	Historic record of possible archaeological interest with no corresponding geophysical anomaly

Table 2 Criteria for discriminating relevance of seabed features to proposed scheme

5.6.4 All the sites that have been identified by the 2012 survey within the study areas are presented in Appendix 2.0 and discussed in this report. The locations of the 2009 anomalies are summarised in Appendix 2.0.

5.6.5 The grouping and discrimination of information at this stage is based on all available information and is not definitive. It allows for all features thought to be of archaeological interest to be highlighted, while retaining all the information produced during the course of the geophysical interpretation for further evaluation should more information become available.

5.7 SIDESCAN DATA PROCESSING

5.7.1 Data was sub-sampled across-track to create 4000 pixels per swath with a nominal size of 1.56cm across track. This was done to improve the across-track imagery signal-to-noise ratio, by removing sonar speckle. The along-track ping period was 0.037sec which when combined with the average speed over the ground (3 knots) gives ping spacing of 5.5cm along track.

5.7.2 The processing had several stages to the mosaic creation:

- Merging of boat navigation and data with the imagery and calculation of the transducer position relative to the GPS transponder. Various assumptions are applied: the offset was assumed to be constant and defined by the heading of the boat and not the boat's track.

- A slant-range correction was applied and used a speed of sound of 1470m/s as this seemed to correlate seafloor features well from two parallel swaths. An assumption that that seafloor is essentially flat across-track which was within the error bounds for this calculation (over 5° slope would need true slant-range correction).

- Across-track equalisation of illumination on an equal range basis. This assumes that the imagery from a particular range should average a given amount for each piece of data. The near-range pixels and far-range pixels are generally darker than mid-range pixels. This is due to the transducer's beam pattern and differences in seafloor backscatter response in terms of angle of incidence. The result of this is to amplify the near and far-range pixels by about 1.5 and reduce the mid-range pixels by 0.8. These values are calculated from the individual segment being processed. Values are normalised to a pixel value of 1000.

- Filtering of data for line-dropouts, where insonification direction is affected by directionality of the returning beam – usually due to excessive boat movement. High Pass filter of the imagery taking a kernel of 1 line by 351 pixels and subtracting the average from the central pixel. Valid pixels have values between 1 and 5000. Low Pass filter of the imagery taking a kernel of 31 line by 351 pixels and storing the average in the central pixel. Valid pixels have values between 1 and 5000.

- Weighted combination of the high and low pass filters by addition of pixels.

  i.e. $X_{new} = 1 * (Average_{large\ area}) + 1 * (X_{old} – Average_{line})$

- Reduction of the across-track resolution to the required resolution by averaging of pixel values. A 10 to 1 reduction in resolution across-track will increase signal-to-noise ratio by over three times.

- When data is placed on the mosaic it is often seen that some very small patches of seafloor seem to be not insonified. Holes of 1-2 pixels are filled with interpolated data from its immediate neighbourhood. To stop the interpolated areas appearing smooth some variance is added to the interpolated pixels.

5.7.3 The data covers a large area (comparatively for the resolution) and thus the data was divide into 19 maps (with overlap) – Figure 12. Each map equates to about 16 million pixels at 10cm resolution (about 32Mb). Again smaller but higher resolution maps were defined over the main feature sites at 2cm resolution. If the 19 maps were done at this higher resolution each area would be about 800Mb and would have to be printed on a 3m by 3m chart (at 600dpi).

5.7.4 Initially therefore the data was processed at a 10cm resolution for the whole survey thus allowing enough data to fill every pixel in the mosaic imagery without interpolation, and being able to see all the relevant features from the survey. A second resolution processing was done at 2cm for areas of interest. This requires a certain amount of along-track interpolation but also allows the full resolution of the sidescan imagery to be viewed.

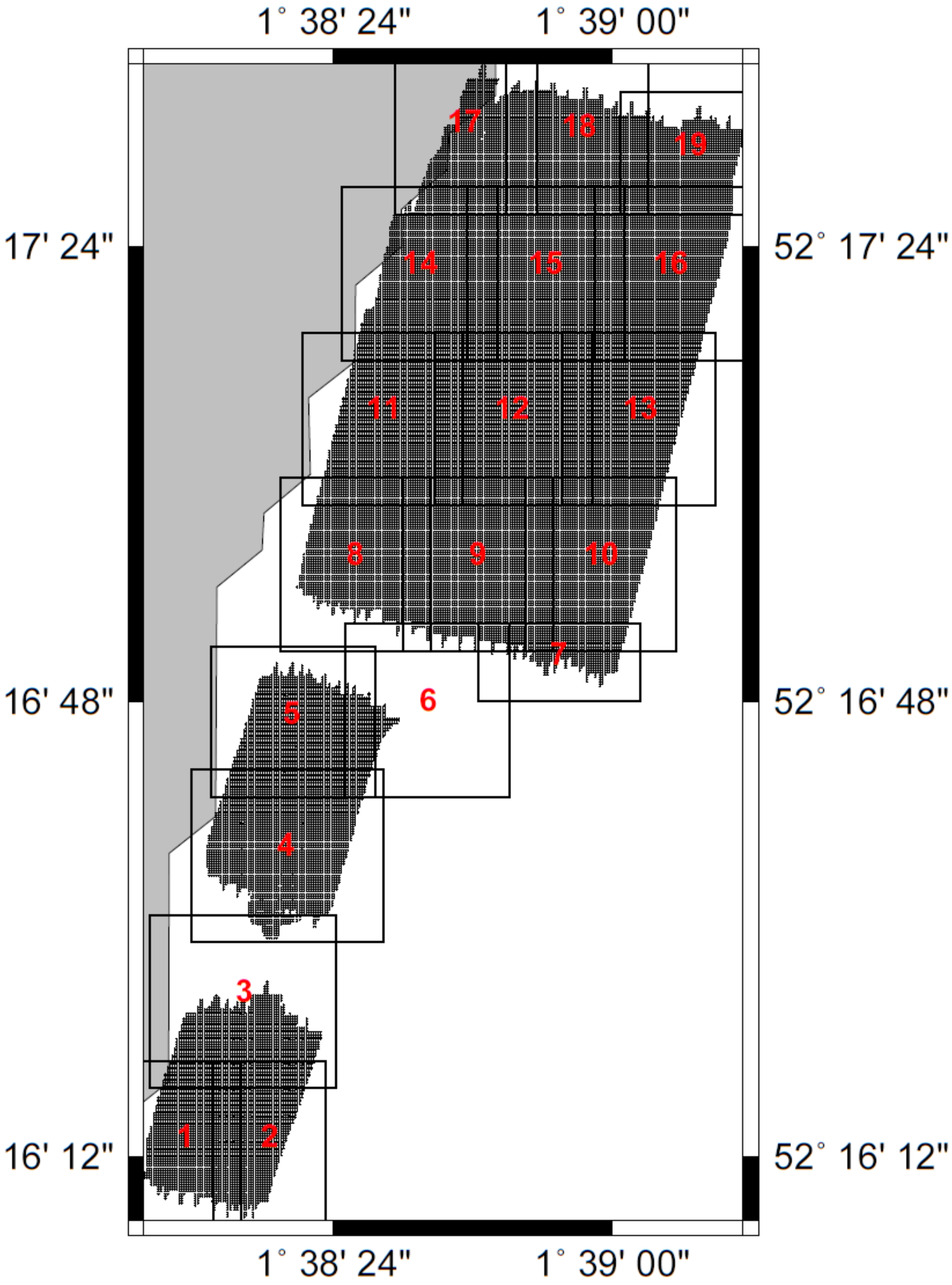


Figure 12 Sidescan and MBES processing was divided into 19 area of manageable sizes and then stitched together to create 3 distinct areas

5.7.5 During the processing it was seen that the features of adjacent lines overlapped well but required manipulation of sound speed of water which had been previously assumed to be 1500m/s but turned out to be considerably less at about 1470m/s. Equalisation of illumination was applied to the data to remove any range effects. Sidescan sonar suffers from a characteristic that makes the imagery closest to the vehicle (nadir) of very poor quality. Fortunately the sidescan survey was captured with very closely spaced lines and it was sometimes possible to use the far-range imagery in place of the nadir imagery and thus create a better mosaic (Figure 13).

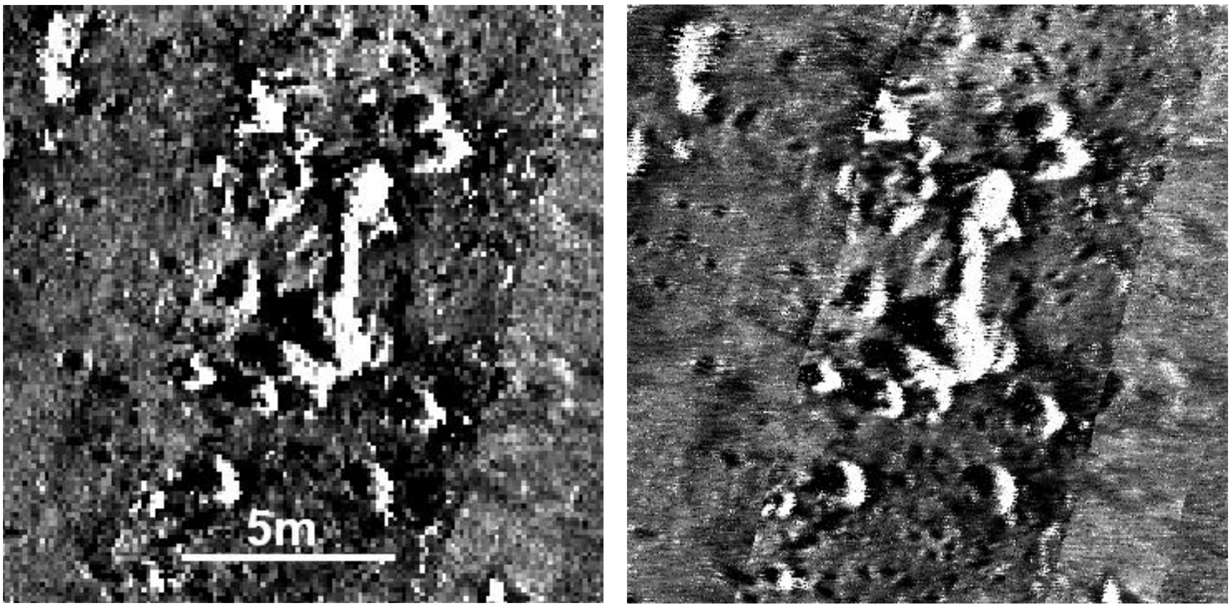


Figure 13 Comparison of 10cm and 2cm resolution sidescan sonar imagery over part of the St Katherine's Chapel site. The mosaic is made from at least 3 sidescan passes.

5.8 Diver held DIDSON surveys 2010-2012

5.8.1 As the water at Dunwich is very turbid it is not possible for diver or a ROV to photograph the seafloor using conventional optical cameras. For this application we deployed the Soundmetrics DIDSON (Dual frequency IDentification SONar - DIDSON) acoustic imaging camera. These systems have arisen from the demand for better imaging in turbid waters which has led to the development of systems that are able to provide near-video quality images with sound (sonar). In the same way that light waves can refract, sound waves have the same property. They can therefore be focused with an acoustic lens system in the same way that light is focused with optical lenses, principally by moving one of the lens elements. The result is an acoustic image with significant detail. In many ways, the acoustic camera (DIDSON) bridges the gap between conventional sonar's that can image a shipwreck at 300m and medical ultrasound which can image inside the body at a range of 10cms.

5.8.2 Acoustic cameras operate using a combination of high frequencies, acoustic lenses and very narrow beams to increase the detail in images. The operating frequencies range up to 3MHz with the high frequency sound being more quickly absorbed in the water than low frequency sound. As a consequence, the range of these high-frequency acoustic cameras is limited to around 40m when operating at 1.1MHz and approximately 15m when operating at 1.8MHz.

5.8.3 The DIDSON systems can focus from as close as 1m, to its maximum range of 40m. Its major limitation, however, is that it only has a 29 deg field of view, leading some users to call it an "acoustic torch". This relatively narrow beam means that while the DIDSON is a good identification tool, it is not such a good search tool. Therefore, side scan sonar's etc., are conventionally employed to locate the targets of interest. This leaves the DIDSON to follow up and make the positive identification. The various DIDSON systems have been mounted on fixed bottom mounts, AUVs, ROVs and held by divers as described in this application.

Figure 14 DIDSON Diver Held (DH) System showing head-up display on dive mask. Diver Andy Rose (LearnScuba) with DIDSON technical support Mike Sawkins (McArtney).

5.8.4 The DIDSON DIVER-HELD (DH) system used in this survey is a self-contained unit used with rechargeable batteries and a mask-mounted display (Figure 14). It has a depth rating of 100 m. The DIDSON-DH System allows divers to operate in zero-visibility conditions. The diver views the image through a mask-mounted SVGA colour display. The rechargeable, exchangeable batteries provide ~2.5 hours of operation. Further specifications are available from the Soundmetrics website http://www.soundmetrics.com/products/imaging-sonars/didson-diver-held.

5.8.5 DIDSON sonars operate at two discrete frequencies: a higher frequency that produces higher resolution images (Identification Mode), and a lower frequency that can detect targets at further ranges but at a reduced image resolution (Detect Mode). The Diver Held model (DIDSON-DH) used in this study was operated in high-frequency mode (1.8 MHz) to achieve maximum image resolution.

5.8.6 The resolution of a DIDSON image is defined in terms of down-range and cross-range resolution, where cross-range resolution refers to the width and downrange resolution refers to the height of the individual pixels that make up the DIDSON image. Each image pixel in a DIDSON frame has (x, y) rectangular coordinates that are mapped back to a beam and sample number defined by polar coordinates. The pixel height defines the down-range resolution and the pixel width defines the cross-range resolution of the image.

5.8.7 ‘‘Window length’’ (i.e., the range interval sampled by the sonar) controls the down-range resolution of the DIDSON image. Because the DIDSON image is composed of 512 samples (pixels) in range, images with shorter window lengths are better resolved (i.e., down-range resolution=window length/512). Window length can be set to a range of lengths according to the mode of detection (see Table 3). For this study, window length is set at a range of 1-15m HF Identification mode and 1-35m in LF Identification mode. Since we used the coordinates for the centre or margins of the sites shown on MBES or SSS as drop off points for the shot lines used by the divers, the divers were always close to the structure of interest. For this reason we found that High Frequency Identification Mode at 15m gave the best compromise that allowed coverage of a reasonable distance while still operating in high-frequency mode for optimal resolution.

5.8.8 The down-range resolution (or pixel height) for a 10-m window length is 2 cm (1,000 cm/512) and 0.9cm for a 5m window. The cross-range resolution is primarily determined by the individual beam spacing (0.3°) and beam width (0.4°) for the DIDSON-DH at 1.8 MHz. Targets at closer range are better resolved because the individual beam widths and corresponding image pixels increase with range, according to the formula

$$X = 2R \tan(\theta/2)$$

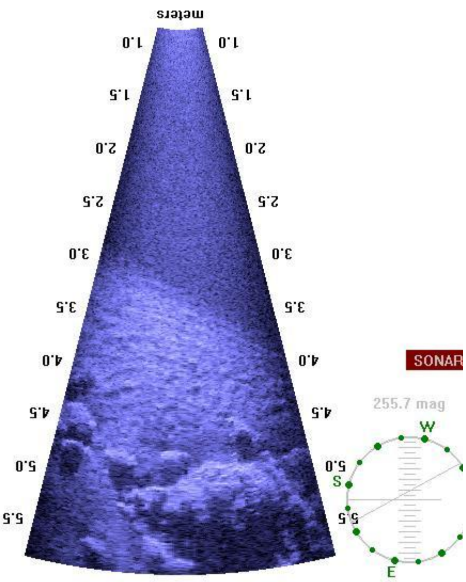
5.8.9 where X is the width of the individual beam or ‘‘image pixel’’ in meters, R is the range of interest in meters, and θ is the individual beam angle in degrees (approximately 0.3°). Horizontal image pixel resolution ranges from 1cm at 2m range to 5cm at 10m range.

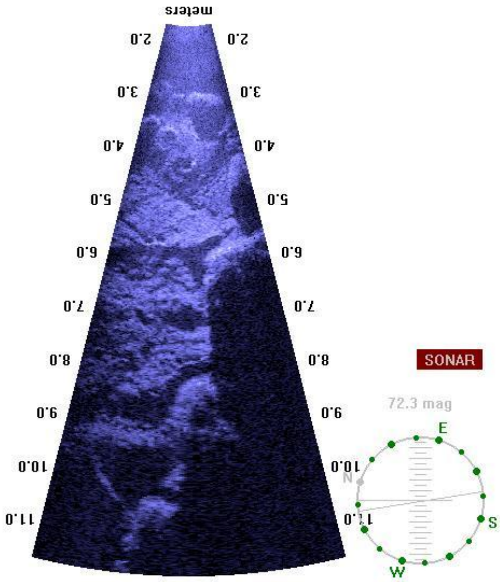
5.8.10 The transmitting power of the DIDSON sonar is fixed, and the maximum receiver gain (40 dB) was used during all data collection. The DIDSON-DH was enabled so that the sonar automatically set the lens focus to the midrange of the selected display window (e.g., for a window length of 15 m that started at 5 m, the focus range would be (15 m – 5 m)/2). The image smoothing feature was disabled. Image display threshold and intensity settings were selected that optimized the contrast of the image (threshold = 10, intensity = 50).

Detection Mode
Operating Frequency 1.1 MHz
Beamwidth (two-way) 0.4° H by 14° V
Number of Beams 48
Beam Spacing 0.6°
Window Length 5m, 10m, 20m, 40m
Range Bin Size (relative to window length) 10mm, 20mm, 40mm, 80mm
Identification Mode
Operating Frequency 1.8 MHz
Beamwidth (two-way) 0.3° H by 14 ° V
Number of Beams 96
Beam Spacing 0.3°
Extended Range Settings
Start Range 0.42m to 26.1m in 0.42m steps
Window Length 1.25m, 2.5m, 5m, 10m
Range Bin Size (relative to window length) 2.5mm, 5mm, 10mm, 20mm

Table 3 DIDSON-DH specifications. Most data at Dunwich were captured in Identification model operating at 10m range. Data from Soundmetrics 2013.

5.8.11 The first trials of the diver held DIDSON on non-wreck marine archaeology were conducted at the Dunwich tide site in 2009. These initial tests included diver training. A field visit to the Dunwich town site took place in poor conditions that prevented diver deployment. Instead the DIDSON was deployed by hand over the side of a RIB. The water depth of <10m over the site is well within the 11-25m range of the DIDSON. Images were poor, but sufficient to confirm that the system was capable of imaging objects on the seabed at the Dunwich site.





at the St Peter's church site. Note different scales.

5.8.12 For the 2012 survey the DIDSON was mounted on a swivel-plate and attached to a tripod. This would then be stood on the seafloor and the system rotated on the plate. This would produce a video of a circle of any seafloor features.

5.8.13 DIDSON surveys were undertaken in June and July 2010 as part of BBC One Show (June) and BBC Oceans (July) filming at the Dunwich site. On both occasions, divers were deployed over each site and a suite of acoustic videos taken (Figure 15). These confirmed the ability of the DIDSON system to visualise the seabed and associated archaeology.

5.8.14 In March 2012, diver held DIDSON experiments were planned, using a tripod mount. The intention was to delivery the DIDSON attached to the tripod to the seabed. The DIDSON would be set at a known angle and the tripod at a known elevation above the seabed. The diver would then rotate the DIDSON 360 degrees while capturing data. The position of the tripod would be identified from high resolution MBES survey in which the tripod would be visible.

5.8.15 During the first attempt, problems with the Tripod mount were identified. In effect it was too light and top heavy to safely deploy with the DIDSON attached. Similarly, the rolling characteristics of the *Wessex Explorer* on the day, were unsuitable for safe diver operating in the sea conditions at the site. A decision was taken to modify the deployment plan in two ways; first the DIDSON would be deployed without the tripod, with the diver holding it at a known position on the seafloor, and executing a slow 180 degree turn at a fixed height, making every effort to stabilise the system against the diver’s body. Secondly, a new vessel was hired, which had stern diver access, water jets rather than propeller drive, and better roll characteristics for the conditions experienced at the site.

5.8.16 Diver held DIDSON operations were untaken the following day and followed the Dive Plan. Shotlines were dropped at four points around the St Katherine’s Chapel site. These were located using the R2Sonic MBES. At slackwater (evidenced by the lack of movement of the shot line buoys) the Diver (Andy Rose from Learn Scuba) clipped on to a shotline and descended to the bottom with the DIDSON. Once at the bottom the diver conducted a series of imaging sweeps at High and Low frequency. Once completed, the diver ascended, unclipped and swam to the next shotline and repeated the procedure. A safety diver was on standby at all times, and dive times / checks were made from the dive master in the dive boat. Diver and equipment were recovered without incident, and the data saved onto laptop by Mike Sawkins (McArtney AS).

5.8.17 Conditions on the seabed were typical for the site, with zero visibility, and a strong northerly current even at slack water. This affected the ability of the diver to remain stationary, and to conduct sweeps with the DIDSON once the equipment was side on to the current. In effect the current caused the diver to turn more rapidly and with less control.

5.8.18 During the afternoon, sea conditions worsened and a second dive planned for the low flood tide to compensate for the time lost the previous day was cancelled. Diver plus equipment were returned to base at Lowestoft.

5.9 DIDSON PROCESSING

5.9.1 To map this data two assumptions were made. Firstly, that the diver rotated on a single spot, with the camera's focal point exactly one metre from a central rotational point and secondly, that the camera was one metre above the seafloor. Obviously this is not likely to be exact and will introduce error in the map image. Lastly the position of the diver was not well known and thus any imagery was georeferenced to the sidescan and multibeam imagery.

5.9.2 As a series of data frames each frame can be positioned according to the attitude data of heading, pitch, roll and the tripod location and height. A program was created to read in each video frame. Since much of seafloor was visible on many frames it was decided that a filter would be used to stop overlaying of imagery. The middle section of each frame was extracted and then only used if there was no imagery already on the final map. If only a small amount of overlap was present the frame was also kept. A second filter was applied when the tilt of the system was either less than 5 degrees or greater than 20 degrees, thus removing imagery when the diver was getting in position.

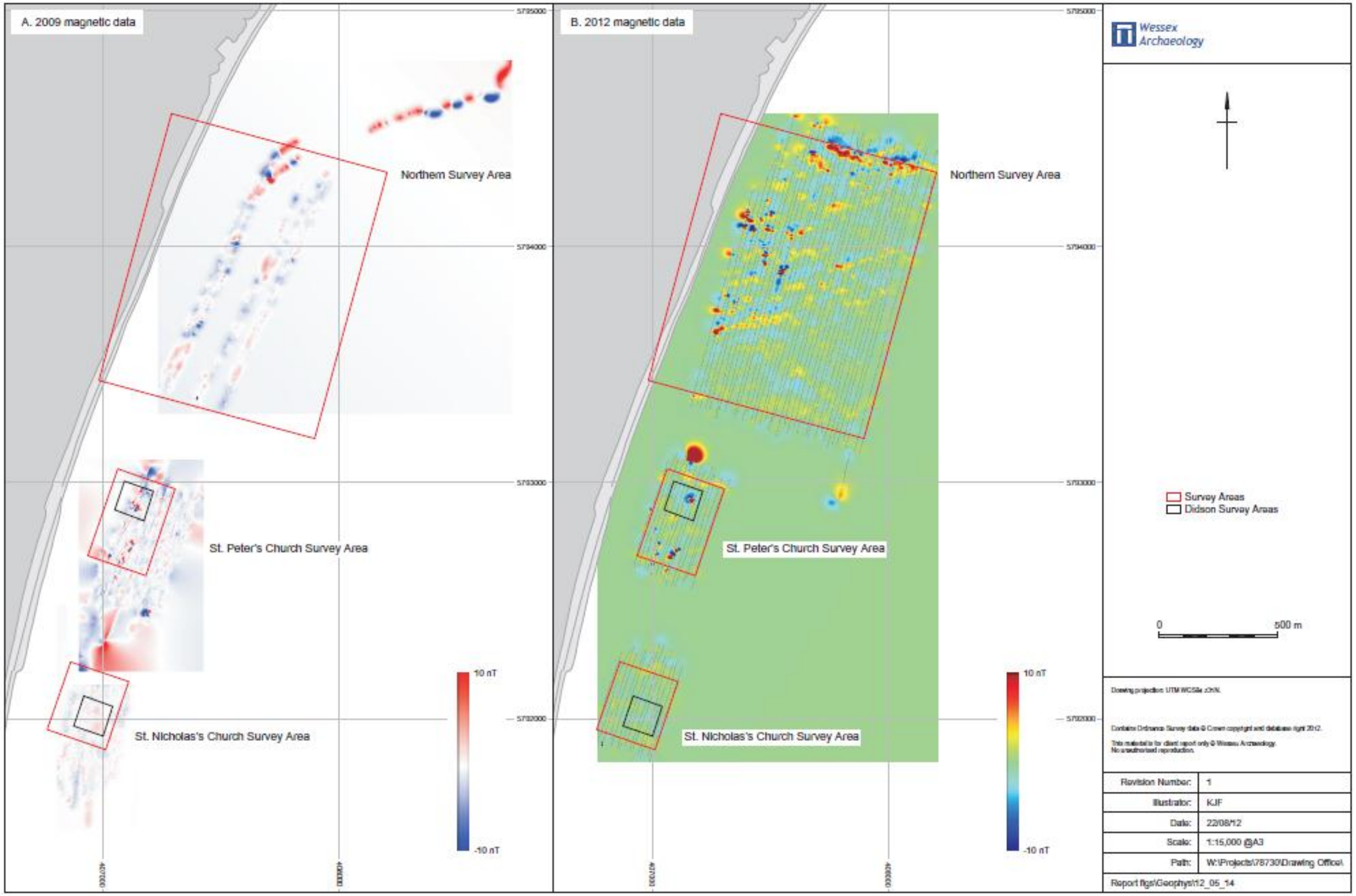


Figure 16 Magnetometer survey results from 2009 (left) and 2012 (right). Re boxes denote the Sidescan and MBES areas undertaken or the 2012 survey.

6 DATA SYNTHESIS

6.1 MAGNETOMETRY RESULTS

6.1.1 A total of 71 anomalies were identified when processing the magnetic data. Since neither the sidescan sonar nor bathymetry datasets were processed by Wessex Archaeology there are no corresponding anomalies to help identify the source of the magnetic responses. As a result all 71 anomalies have been designated A2 as they are of uncertain origin.

6.1.2 The results of the 2012 magnetic survey have also been compared to a similar survey conducted in 2009 (Figure 16). The 2009 survey results identified 11 anomalies, with similar distribution to the 2012 survey. The distributions of anomalies identified in the 2009 and 2012 datasets can be seen in Figure 17. The full results of the 2009 survey are available as part of the *East of England Designated Wrecks: Marine Geophysical Survey and Interpretation* report (WA 2010).

6.2 NORTHERN SURVEY AREA

6.2.1 Of the 71 anomalies identified 51 are located within the northern survey area (7000–7050). Most of these anomalies are located in the central region of the survey area near the shore, with a secondary cluster at the northern limit of the survey area and a more diffuse spread to the south. The anomalies to the north are partially masked be geological trends which may be associated with sand ripples (7032).

6.2.2 The northern cluster is composed of 15 anomalies (7000, 7019, 7027, 7028, 7032-7036, 7039, 7043, 7044, 7046, 7049 and 7050). These anomalies generally range from 7.2nT for 7049 to 28.7nT for 7000. 7028 is an outlier to this range with a higher magnetic amplitude of 214.3nT. This anomaly is located approximately 60m from the northern limit of the survey area and 390m from the coastline.

6.2.3 There are 32 anomalies in the central region of the northern survey area (7001, 7002, 7004 – 7018, 7020 – 7026, 7029 – 7031, 7037, 7038 and 7040 – 7042). These anomalies are all located within 680m of the shore and most have magnetic amplitudes below 100nT. Among these centrally located anomalies 7005, 7006, 7012 and 7029 have magnetic amplitudes over 100nT. Anomalies 7005, 7006 and 7012 are all located at the western limit of the survey area in shallow water. These anomalies have magnetic amplitudes ranging from 105.1nT for 7005 to 283.5nT for 7006. 7029 is located approximately 210m southeast of 7012, and has a magnetic amplitude of 244.2nT.

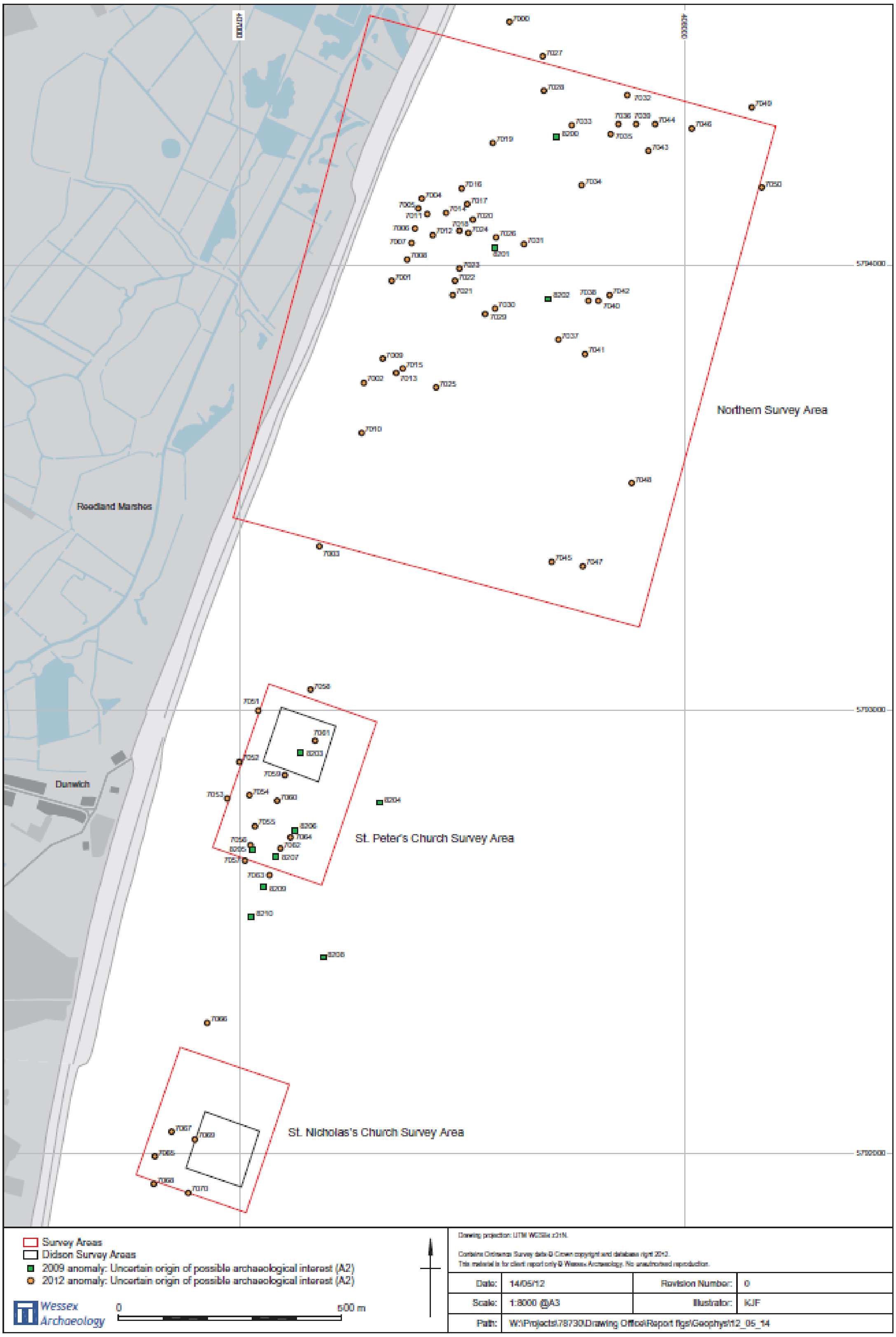


Figure 17 All magnetic targets identified from the surveys in 2009 and 2012. Note the clustering around the St Peter's and St Nicholas churches, and in the northern area of the site.

6.2.4 The remaining four magnetic anomalies (7003, 7045, 7047 and 7048) are widely spread over the southern region of this survey area. 7003 has the highest magnetic amplitude of these anomalies at 19.1nT and is located closest to shore on the southern limit of the survey area. Anomalies 7045, 7047 and 7048 are located at least 520m east of 7003 and have magnetic amplitudes ranging from 5.1nT to 7.1nT.

6.2.5 Only three magnetic anomalies were identified in this area in the 2009 survey. Anomalies 8200, 8201 and 8202 are located in the near the centre of the survey corresponding to areas of high magnetic activity identified in the 2012 survey (Figure 17). The locations of anomalies identified in both surveys do not correspond exactly and it cannot be said with certainty if the same anomalies have been identified in different surveys.

6.3 St. Peter's Church Survey Area

6.3.1 There are 14 magnetic anomalies in the St. Peter's Church survey area (7051 – 7064) (Figure 17). These anomalies are widely distributed across the western side of the survey area, corresponding to the proposed limits of historic Dunwich (Sear, et al., 2011). Most of these anomalies (7051 – 7060) have magnetic amplitudes ranging from 5.4nT to 25.3nT. Anomalies 7062 to 7064 have magnetic amplitudes ranging from 30.9nT for 7063 to 74.4nT for 7062.

6.3.2 7061 has the highest magnetic amplitude among the anomalies observed within the St. Peter's Church survey area at 124.4nT. This anomaly is located near the centre of the northern part of the survey and is located near the proposed location of St. Katherine's Chapel (Sear, 2011).

6.3.3 Eight anomalies were identified in this area following the 2009 survey (8203 – 8204). Although the results of the 2009 and 2012 surveys are similar it is unclear whether the same anomalies have been identified in the separate surveys.

6.4 St. Nicholas' Church Survey Area

6.4.1 The remaining six magnetic anomalies are located in the St. Nicholas's Church survey area (7065 – 7070). These anomalies are distributed across the southwest corner of the survey area within the proposed settlement boundaries (Sear et al., 2011). These are all relatively small anomalies with magnetic amplitudes ranging from 5.2nT for 7068 to 15.1nT for 7065. Anomaly 7069 has a magnetic amplitude of 12.4nT and is located on the western limit of the southern DIDSON survey area near the suggested location of St. Nicholas's Church (*ibid.*).

6.4.2 There were no magnetic anomalies recorded in this survey area as part of the 2009 survey.

6.4.3 A total of 71 magnetic anomalies were identified during the course of the 2012 survey over the submerged remains of the medieval town of Dunwich. Although the nature of these anomalies cannot be ascertained without further investigation their presence does suggest that ferrous objects of possible archaeological origin may be buried in the sands overlying the site.

6.4.4 Although there are some geological trends in the data, possible caused by sand ripples, the majority of anomalies are seen as isolated features. The 2012 magnetic dataset is similar to that obtained in 2009 although more anomalies have been identified in 2012. This similarity suggests that the larger anomalies identified have probably remained static between surveys and are less like to be modern debris shifting on the seabed.

6.4.5 The majority of anomalies lie within the proposed historic coastline (Sear et al., 2011), further suggesting that they may be related to the archaeological remains of the submerged town. Large anomalies, 7061 and 7069, have also been identified near the possible sites of St. Katherine's Chapel and St. Nicholas's Church respectively, and may be associated with their remains.

6.4.6 The distribution of anomalies in the north of the site though possible archaeology, are also likely to be connected with military activity in the area during WWII. Ordnance has been found across the site (notably St Peter's Church site). Furthermore, there are records of gun practice across the Dingle and Dunwich marshes that may explain some of the anomalies. In WWII, metal "dragons teeth" were embedded along the coastline, which may also explain some of the near shore anomalies in the north of the site (Comfort 1994).

6.5 IDENTIFICATION OF NEW MARINE ARCHAEOLOGY

6.5.1 All Multibeam and Sidescan geophysical datasets were reviewed and the potential building remains were identified and demarcated using the polygon tool in ARCMAP 10.1. We compared each target to the Sidescan and Multibeam characteristics from known ruins (i.e. those that had been confirmed by DIDSON and / or Diver survey). In addition, we identified features that had straight/ right angle corners or circular elevated ridges. We also noted where sub-bottom sonar surveys showed the presence of palaeochannels at or immediately below the surface. We screened the data for geological formations (peat rafts/outcrops, or Norwich crag) by comparing sidescan/MBES images from known geological features with touch/visual diver surveys from 2008, 2010 and 2012.

6.5.2 For each target we reviewed whether there was evidence present in each dataset and used this to provide a numerical (1 - 5) confidence value. If a feature is present in all datasets and across all survey dates, then we can have a high confidence that the feature is not an artefact of the data capture/processing, and is a real upstanding or incised object on the seabed. However, we also recognised that a qualitative assessment was necessary since in some cases exposure of new features occurs, and the evidence in the geophysical data is strong. Finally, a description of the data was made. Additional visual evidence was available for some sites based on the diver surveys of Bacon & Bacon (1979, 1988), Historic Wreck Recovery (in 2008), Learn Scuba (in 2009 - the latter taking place in rare good visibility permitting colour video capture (Sear 2013)), and DIDSON data captured in 2010 and 2012.

6.5.3 A total of 79 potential archaeological features were identified across the site, together with evidence of five palaeochannel cross-sections (Table 4, Figure 18). Of the 79 sites, we have been able to positively identify the ruins of St Peter's church (2), Blackfriars friary (18 – 22, 29 – 31, 46) and St Nicholas church (12, 13, 14, 32). We have also identified a building likely to be St Katherine's chapel (0, 1) although its position is further west than Gardner (1754) records for its possible date of loss over the cliffs (c. 1550).

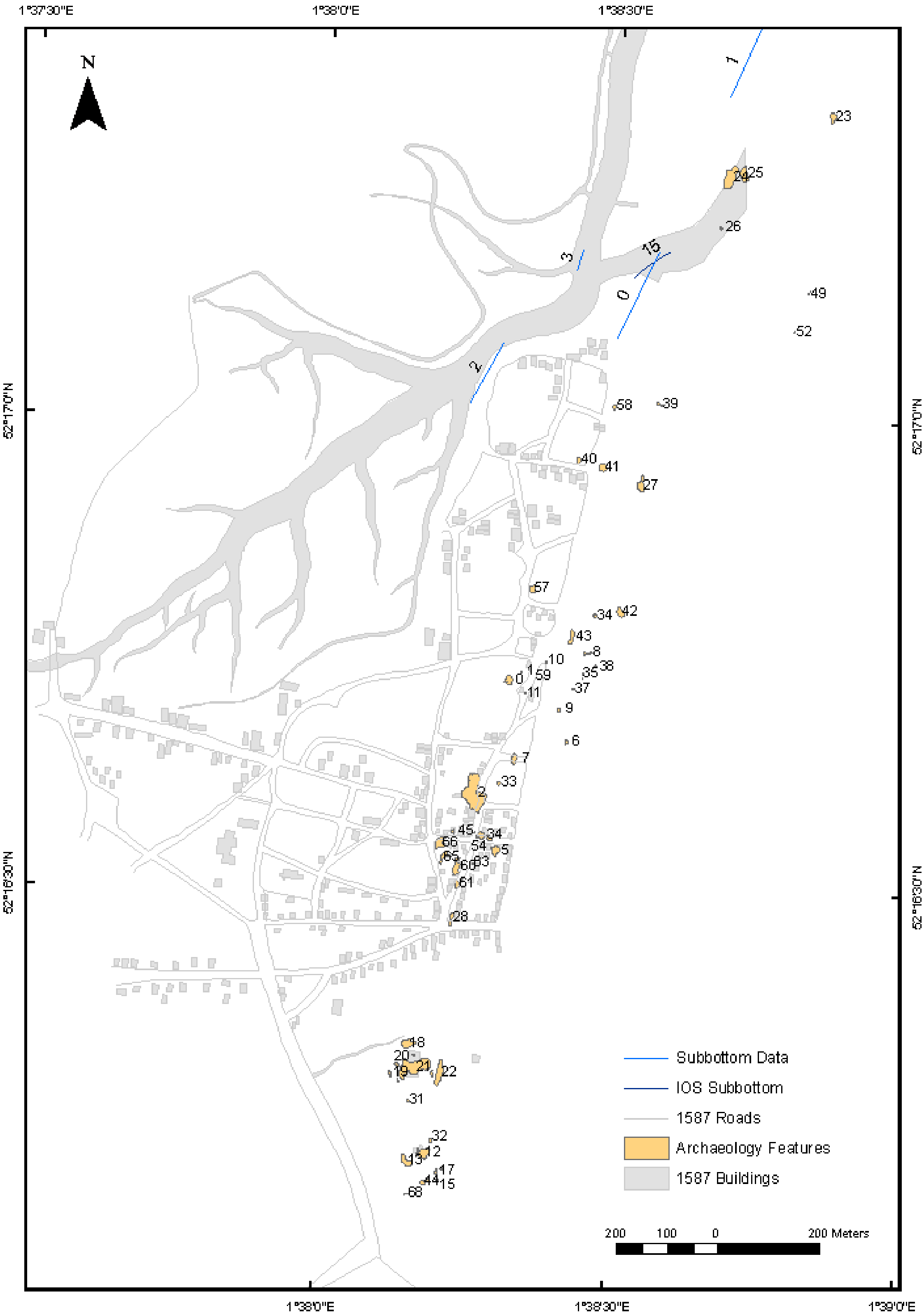


Figure 18 Summary of archaeological features identified on the geophysical surveys available from 2008 – 2012. Table 4 provides a summary of the features. Most of the larger ruins lie within the limits of the 1587 Agas map. However, 15 sites lie east of the limits of this map and are therefore important for understanding the earlier town.

ID	SSS	MBES	Magnetic Target	Sub Bottom	Diver / DIDSON	Confidence Index/Level	Description
0	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012	WA 2009 8203	NC	Diver Bacon (1988) DIDSON 2010 DIDSON 2012	9/H	Possible site of St Katharine's Chapel, though predicted loss (16xxx) would have been much later than stated in records (c.1550) which casts doubt on its identification. However, Bacon (1988) recovered carved ecclesiastical stonework from site. Bacon wrongly identified the site as the chapel of Maison Dieu.
1	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5/H	Discrete block with scour hole around it. May be linked with Site 0.
2	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012	WA 2009 8205, 8207 WA 2012 7056, 7062	NC	Diver (Bacon etc.) Rc. Diver (HWR / LS) Film Diver DIDSON 2010	10/H	St Peter's Church. Divers made visual observations, partially mapped the site and recovered carved stonework in the 1970's (Bacon & bacon 1988). The site was filmed using optical and acoustic imaging cameras in 2009 & 2010).
3	EMU 2008 WA 2012	EMU 2008	WA 2012 7063	NC		4/H	Group of discrete blocks c. 1.0 x 0.6m. Similar to Sites 0 and 2. Agas 1587 map shows several large buildings in vicinity. Toll house?
4	EMU 2008 WA 2012	EMU 2008 WA 2012		NC		4/H	Group of large (2.0-1.0m) and some smaller blocks. Evidence of sediment streaks/scour in direction of tidal currents. Agas 1587 map shows several large buildings in vicinity.
5	WA 2012	WA 2012		NC		2/M	Scoured area of seabed with some small blocks, and a larger block shown in WA 2009 Sidescan. Agas 1587 map a large building in vicinity.
6	WA 2012	WA 2012		NC		2/L	Discrete raised block but might be part of geology. Lies in pre-Agas (1587) area of town.
7	WA 2009	WA 2012	WA 2009	NC		4L	Depression with straight raised features

	WA 2012		8206				within, some with near right angled corners. Lies east of Market place. Could be geology.
8	WA 2012	WA 2012		NC		2M	Depression with small blocks (0.6 x 0.4m) within it. Lies in pre-Agas (1587) area of town.
9	WA 2012	WA 2012		NC		2/M	Scour hole with blocks in it similar to other building sites but less extensive. Lies in pre-Agas (1587) area of town.
10	WA 2012			NC		1M	Collection of c. 3 blocks (0.7 x 0.5m) with scour holes around them. Lies of eastern margin of Agas 1587 coast line.
11	WA 2012			NC		1L	Raised mound c. (1.6 x 0.5m).
12	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC	DIDSON 2010	6H	St Nicholas Church. Divers recovered stones with medieval mortar from this site in 2008. The site was filmed using DIDSON acoustic imaging cameras in 2010. Large blocks, some with flat/straight sides.
13	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5H	St Nicholas Church. Smaller block field 34m to south west of main ruins (12)
14	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5H	St Nicholas Church. Smaller block field to west of main ruins (12).
15	WA 2012	WA 2012		NC		2H	Small group of smaller blocks (0.6 x 0.3m) 57m southeast of main ruins. Separate building from St Nicholas?
16	EMU 2008 WA 2012	WA 2012		NC		3H	Small group of 2 blocks (1.6 x 0.4m) 34m southeast of main ruins. Separate building from St Nicholas?
17	WA 2009 WA 2012	WA 2012		NC		3H	Group of blocks (1.6 x 0.3m) 40m southeast of main ruins. Separate building from St Nicholas?
18	EMU 2008 WA 2009 WA 2012	WA 2012		NC		4H	Blackfriars Friary (New). Collection of smaller blocks (< 0.5m) and stones emerging from a sand rib. North west of

							main Blackfriars ruins. Part of Friary buildings?
19	WA 2009 WA 2012	EMU 2008 WA 2012		NC		4L	Blackfriars Friary. 1.6m x 0.7m block emerging from sand rib.
20	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5M	Blackfriars Friary. Group of 4 blocks one 2.3 x 0.4m, emerging from sand rib. Lies to west of main ruins.
21	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC	Diver DIDSON	5H	Blackfriars Friary. Main block field. Large blocks up to 5m length, with scattered smaller stone/block fields. Lies in area of exposed geology. Divers took DIDSON acoustic images confirming block field in 2010.
22	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5H	Blackfriars Friary. Scattered blocks (0.8 x 0.6m) with sand streaks. Part of Blackfriars buildings. Lies East of main Site (21).
23	WA 2009 WA 2012	*NC 2008*		NC		2L	Group of block like sidescan features. possibly partly buried. Geology?
24	WA 2009 WA 2012	*NC 2008* WA 2012	WA 2012 7029, 7030	NC		3L	Probable outcrop of estuarine clay/peat. But some features suggest wreck like structure? In area of former estuary.
25	*NC 2009* WA 2012	*NC 2008* WA 2012		NC		2H	Blocks and linear straight ridges with right angle corners. Associated with 24? In area of former estuary.
26	*NC 2009*	*NC 2008* WA 2012		NC		1L	Single block in scoured area. Probably peat block? In area of former estuary.
27	WA 2009 WA 2012	WA 2012		NC		3M	Area of linear straight and curved ridges, including circular 2m diameter structure (well?).
28	EMU 2008 *NC 2009*	EMU 2008 *NC 2012*		NC		2H	Linear area of scour with large blocks in vicinity of Kings Street/Duck lane junction where Agas shows several large buildings.
29	EMU 2008 WA 2009 WA 2012			NC		3M	Blackfriars Friary. Group of three small (0.5 x0.3m) blocks emerging from Sand streak. Part of Blackfriars complex.

30	EMU 2008 WA 2009 WA 2012	EMU 2008		NC		4L	Blackfriars Friary Area of raised seabed – possible block?
31	EMU 2008 WA 2009 WA 2012			NC		3L	Blackfriars Friary. Depression with small block features. Not clear. Lies South of main ruins.
32	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5L	St Nicholas Church. Depression in seabed with some small blocks (0.5 x 0.4m). North east of main ruins. Geology?
33	EMU 2008 WA 2009	EMU 2008 WA 2012	WA 2012 7064	NC		4L	Raised mounds (block?) 6m x 2m east of St Peter's Church. Geology?
34	*NC 2009* WA 2012	WA 2012		NC		2L	Discrete raised area (6 x 2m) with some evidence of smaller stones around it. Lies east of Agas 1587 map.
35	WA 2012			NC		1L	Possible small area of blocks.
36	WA 2012	WA 2012		NC		2L	Single block (1m x 0.4m) – low relief as partly buried. Lies east of Agas (1587) map.
37	WA 2012	WA 2012		NC		2M	Block (1.0 x 0.9m) within scour depression with smaller blocks. Part buried. Lies east of Agas (1587) map.
38	*NC 2009* WA 2012	EMU 2008 WA 2012		NC		3L	Shadow of a partly buried block. Lies east of Agas 1587 map.
39	WA 2012	EMU 2008 WA 2012		NC		3M	Linear features with right angles. Foundations? Lies east of Agas 1587 map.
40	*NC 2009*	EMU 2008 WA 2012		NC		2L	Scoured area with large blocks (1.4m). Might be geology?
41	*NC 2009*	WA 2012		NC		1L	Scoured area with large blocks (1.3m). Might be geology?
42	*NC 2009*	*NC 2008* WA 2012		NC		1L	Scoured area with block in it. Might be geology? Lies east of Agas 1587 map.
43		WA 2012		NC		1L	Scoured area with large blocks (1.6m). Might be geology?
44	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5L	Scoured area with some blocks(?). Might be geology? 54m south of main St Nicholas Church ruins

45	EMU 2008 WA 2012	*NC 2012*		NC		2L	Scoured area with some blocks(?). Might be geology?
46	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5L	Blackfriars Friary. Area of possible rubble but complicated by exposed geology.
47	EMU 2008 WA 2009 WA 2012	EMU 2008 WA 2012		NC		5L	Scoured area with some blocks(?). Might be geology?
48	*NC 2009* WA 2012	*NC 2008* *NC 2012*		NC		1M	Large partly buried block (1.3 x 0.9m) with evidence of scour around it. NE of Agas 1587 map.
49	*NC 2009* WA 2012	*NC 2008* *NC 2012*		NC		1M	Large partly buried block (2.2 x 0.8m) with evidence of scour around it. NE of Agas 1587 map.
50	*NC 2009* WA 2012	*NC 2008* *NC 2012*		NC		1L	Small (0.9 x 0.5m) block partly buried. NE of Agas 1587 map.
51	*NC 2009* WA 2012	*NC 2008* *NC 2012*		NC		1L	Small (0.9 x 0.5m) block partly buried. NE of Agas 1587 map.
52	*NC 2009* WA 2012	*NC 2008* *NC 2012*		NC		1L	Large (1.9 x 0.8m) block partly buried. NE of Agas 1587 map.
53	EMU 2008 WA 2009	EMU 2008 *NC 2012*	WA 2012 7063	NC		4H	Large and small block with scours around them. Part of the ruins in site 3
54	WA 2009	*NC 2012*	WA 2009 8209	NC		2H	Two small blocks (0.8 x 0.4m) with scour around them. Part of the ruins in site 3
55	WA 2009	*NC 2012*	WA 2012 7063	NC		2H	Single large block (1.7 x 0.5m) with scour around them. Part of the ruins in site 3
56	WA 2009	*NC 2008* *NC 2012*		NC		1H	Large (1.2 x 0.3m) and small block with scour around them. Part of site 60.
57	EMU 2008	EMU 2008		NC		2L	Area of scour with some smaller blocks. Geology?
58		EMU 2008		NC		1M	Area of scour with single large block (1.4m x 0.4m) exposed in 2008.
59	EMU 2008 WA 2012		WA 2012 7061	NC		2M	Single large block with scour around it.
60	EMU 2008	EMU 2008	WA 2009	NC		3L	Possible area of rubble but likely to be

	WA 2012	*NC 2012*	8210				sidescan/MBES processing error
61	WA 2009	EMU 2008 *NC 2012*		NC		2M	Area of scour with blocks in vicinity of buildings on Agas Map.
62	EMU 2008	*NC 2012*		NC		1M	Single large block (2m) with scour around it in vicinity of buildings on Agas Map.
63	WA 2012	*NC 2012*		NC		1L	Group of 3 small blocks (0.5 x 0.4m).
64	WA 2012	EMU 2008 *NC 2012*		NC		2L	Possible group of blocks with scour around them in vicinity of buildings on Agas Map.
65	EMU 2008 WA 2009	EMU 2008		NC		3M	Area of scour with many small blocks (0.5 x 0.5m) in vicinity of buildings shown on Agas map. Geology?
66	EMU 2008 WA 2009	EMU 2008		NC		3M	Area of scour with many small blocks (0.5 x 0.5m) in vicinity of buildings shown on Agas map. Geology?
67	WA 2009			NC		1L	Single block – one of three (67, 68, 69) in an east-west line.
68	EMU 2008 WA 2009			NC		2L	Single block – one of three (67, 68, 69) in an east-west line.
69	WA 2009			NC		1L	Single block – one of three (67, 68, 69) in an east-west line.
70	EMU 2008 WA 2009			NC		2M	Area of scour with many small blocks (0.5 x 0.5m). Geology?
71	EMU 2008 WA 2009	EMU 2008		NC		3L	Single (0.6m diameter) block (?)
72	EMU 2008 WA 2009 WA 2012	WA 2012		NC		4H	Area of scour with many small blocks (0.4 x 0.3m). Associated with Site 0.
73	EMU 2008 WA 2009			NC		2H	Area of scour with many small blocks (0.5 x 0.3m). Associated with Site 0.
74	WA 2009 WA 2012	EMU 2008		NC		3M	Area of scour with many small blocks (0.5 x 0.3m).
75	EMU 2008 WA 2009 WA 2012	EMU 2008		NC		4M	Area of scour with many small blocks (0.5 x 0.3m).
76	EMU 2008	EMU 2008		NC		3M	Area of scour with many small blocks (0.5 x

	WA 2009						0.3m).
77	EMU 2008 WA 2009		WA 2012 7059	NC		2M	Area of scour with many small blocks (0.5 x 0.3m).
78	EMU 2008 WA 2009	WA 2012	WA 2012 7060	NC		3M	Discrete area of small blocks (0.4 x 0.3m).
79	EMU 2008 WA 2009	WA 2012		NC		3L	Linear feature made of small blocks/stones. Probably geology.
S0	EMU 2008 WA 2009 WA 2012	WA 2012		WA 2009 PM		High	Palaeochannel detected in Profile 1 Parametric Sonar Line. Wessex Archaeology (2009)
S1	EMU 2008 WA 2009 WA 2012	WA 2012		WA 2009 PM		High	Palaeochannel detected in Profile 1 Parametric Sonar Line. Wessex Archaeology (2009)
S2	N	N		EMU 2008 BM		High	Palaeochannel section detected in Profile D118 Boomer Line. EMU Ltd (2008).
S3	N	N		EMU 2008 BM		High	Palaeochannel detected in Profile D137 Boomer Line. EMU Ltd (2008).
S15	EMU 2008 WA 2009 WA 2012	WA 2012		IOS 1975 BM		High	Palaeochannel detected in Boomer profiles. Lees (1980) Report No.66.

Notes: WA = Wessex Archaeology, EMU = Emu Ltd., BM = Boomer, PS = Parametric Sonar, IOS = Institute of Oceanographic Studies, HWR = Historic Wreck Recovery, LS = Learn Scuba, *NC = No data Coverage*. H = High , M = Moderate, L = Low levels of confidence in feature being part of a former building.

Table 4 Archaeological features identified for the Dunwich site based on all available geospatial data.

6.5.4 The 2012 survey has identified six additional sites that are highly likely to be the ruins of buildings. These have either high levels of confidence in identification as ruin like features, and / or high scores for feature presence in multiple geophysical datasets. Only one of these can be ascribed with any confidence to a specific building. Site 18 is most likely to be part of the Blackfriars complex of buildings. Of the other sites, sites 3, 4 and 53 are probably two separate structures from the area of buildings shown on the Agas 1587 map at the junction of Duck Street and Kings street. Bailey identified this area with the site of the Town Hall (Tollhouse), though it would seem more likely that this would be located closer to the Market square. Sites 17 and 18 are part of a structure some 54m south of St Nicholas church. The structures are unlikely to be from St Nicholas Church as material of this size is effectively immobile, neither is it part of South gate as these were wooden structures (West 1970).

6.5.5 Site 25 might be in-situ foundations from a site in the northeast part of the town. This makes it of great interest, since to date there are no structures reported from this area. The foundations of building from the northern part of the town are reported by Gardner (1954) following the storm of 1740, and can also be seen in photographs of the beach taken after the scouring storm of 1911 (Dunwich museum archives). Further investigations are needed to confirm that these are of human origin.

6.5.6 Site 24 is unique, and difficult to interpret. It might be a fragment of the peat surface or marsh sediments that can be seen in the north west of the site. However, the sidescan shows what appear to be horizontal shadows (from posts?) projecting up at regular intervals, or possible horizontal ribs, or it might be a data artefact. Lines of posts are exposed on the foreshore and are probably part of the harbour infrastructure. Alternatively, they might indicate the presence of an unknown wreck site. Further investigation is needed to determine its origin.

6.5.7 The sub-bottom profiles undertaken by the Institute of Oceanographic Science (Lees 1977), EMU LtD (Sear et al., 2008) and Wessex Archaeology (Wessex Archaeology 2009), show the location of old river channels extending from the seabed to depths of 3m. Importantly, they align with the area of the former Dunwich / Blyth river as shown on the Agas Map, and the location of former estuary sediments (peat/clay) in the MBES datasets. Together this information confirms the position and dimensions of the channel. These locate the north west limit the town as shown in the Agas map.

6.5.8 The geophysical surveys demonstrate that the majority of archaeology visible on the seabed using these technologies is composed of blocks of rubble and mortar, and in some cases areas of large cobbles / boulders which have fallen from larger masonry blocks either during collapse down the cliffs, or with dissolution of the lime mortar. None of the conventional geophysics (Sidescan/MBES) was able to identify cut or carved stonework which is known to exist on the site (Sear et al 2008; 2011). DIDSON acoustic imaging sonar and conventional optical filming have been able to identify carved and worked stonework from the sites of St Peter's church and the probable site of St Katherine's chapel. We review this data in the following section.

6.6 DIDSON SURVEYS (OBJECTIVE 3).

O3: To assess the heritage and archaeological value of existing structures identified on the sea floor through novel deployment of high resolution MBES and DIDSON DH technology at the St Nicholas Church and St Katherine's Chapel sites.

6.6.1 In total 62 DIDSON film files have been taken over the Dunwich site, concentrating on the four main ruins. Data redundancy, defined as the number of frames with no useful data in them, varies from 27 – 100% with an average of 58%. The highest redundancy is on the Low Frequency setting, at ranges of 1-23m and at the High Frequency setting with ranges of 1.0-5.5m. the former is largely due to the shallow angles at low elevation over the 23m distance which results in poor resolution at the farthest range and long shadows that tend to obscure data at the lower range. The Higher resolution images resulting from the HF short range setting resulted in close up images with very high intensity returns. The short range also has the maximum redundancy from the unsteadiness imposed by hand-held operation. The optimum settings with the lowest data redundancy are at High Frequency and range setting 1-11.0m.

6.6.2 The Soundmetric DIDSON Diver held acoustic imaging camera was used on specific targets identified by the MBES and SSS. The strategy was threefold:

6.6.3 first, we undertook basic tests to determine if the DIDSON-DH could acquire images of the seafloor and structures in the conditions at Dunwich. Secondly, we used the system to confirm the general nature of the structures and surrounding seabed at each site. This was based on visual assessments of the seabed (presence of ripples, gravels, cobbles, bedrock); the structural materials (presence of blocks, evidence of the composition of the blocks (stone rubble, shape, nature of edges (straight, etc), presence of worked stone, presence of cobble/boulder/stone fields around site). Thirdly, we looked for evidence that would confirm a human origin for the structures as opposed to exposures of local geology. This included the composition (e.g. large blocks made up of smaller cobbles – Figure 20), the presence of straight edges to blocks/stones, 90 degree corners to blocks, and flat faces or carvings on stonework. Figure 20 and 21 shows the form and outline of masonry blocks from All Saint's and St Peter's Churches. The complexity of the outlines results from the erosion of lime mortar from around the framework cobbles and boulders used to make up the rubble infill of the church walls and tower (Figure 19). These are visible in the acoustic shadows in the DIDSON-DH imagery. However, the film of the ruins of St Peter's church reveal that this outline may be softened by the growth of marine organisms (Figure 19). DIDSON sonar is also able to image organic matter (Figure 21b).

Figure 19 Examples of the kinds of blocks of rubble masonry produced by collapse of a stone structure down the Dunwich cliffs. The three beach pictures are screen shots from film footage taken in (top) 1959 and (bottom right) 1970 and hosted on the UEA East Anglian Film Archive. They show ruins of the tower from All Saint's Church. Bottom left is a screen capture from film taken of St Peter's Church ruins in 2009 by Learn Scuba. Note the uneven surfaces to the blocks resulting from erosion of lime mortar matrix from around the cobble/small boulder framework, and the smoothing effect of marine growth over the surface of the equivalent submerged blocks.

6.6.4 The DIDSON-DH surveys provided three types of information:

- Avi film footage from four sites in the form of short sweeps over the ruins.
- Still image capture from the Avi files and image enhancement
- AVI image mosaicing and georectification to generate a 2D map of the St Katherine's Chapel site.

6.6.5 The DIDSON-DH imaging was found to be useful for identification of seafloor conditions around the structures. Most notable was confirmation of the scour pits around individual structural blocks and large cobbles which has been seen on MBES and SSS surveys. The DIDSON-DH film and image capture were able to show features smaller than were visible with other geophysical systems deployed at the site, including ripples in the fine sediments (Figure 20a), bedrock structures (Figure 20b) and organic matter covering the structures (Figure 21b). Worked stone and the random arrangement of the ruined material were also detected (Figure 21a and b).

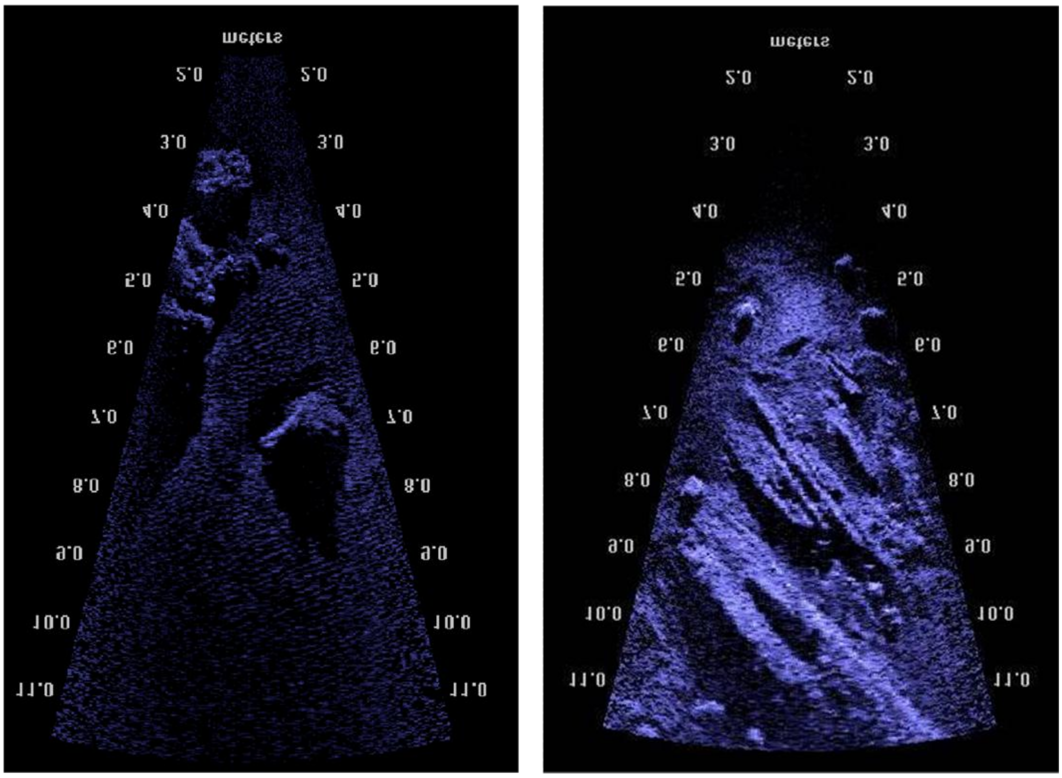


Figure 20 a) DIDSON-DH image of masonry blocks and cobbles at St Katherines church site, showing presence of fine rippled sediment surrounding the site and a scour pit around the foreground block. **b)** Structure in the underlying bedrock at the Blackfriar's site. Large (0.25mØ individual boulders are most likely from the ruins of the Friary.

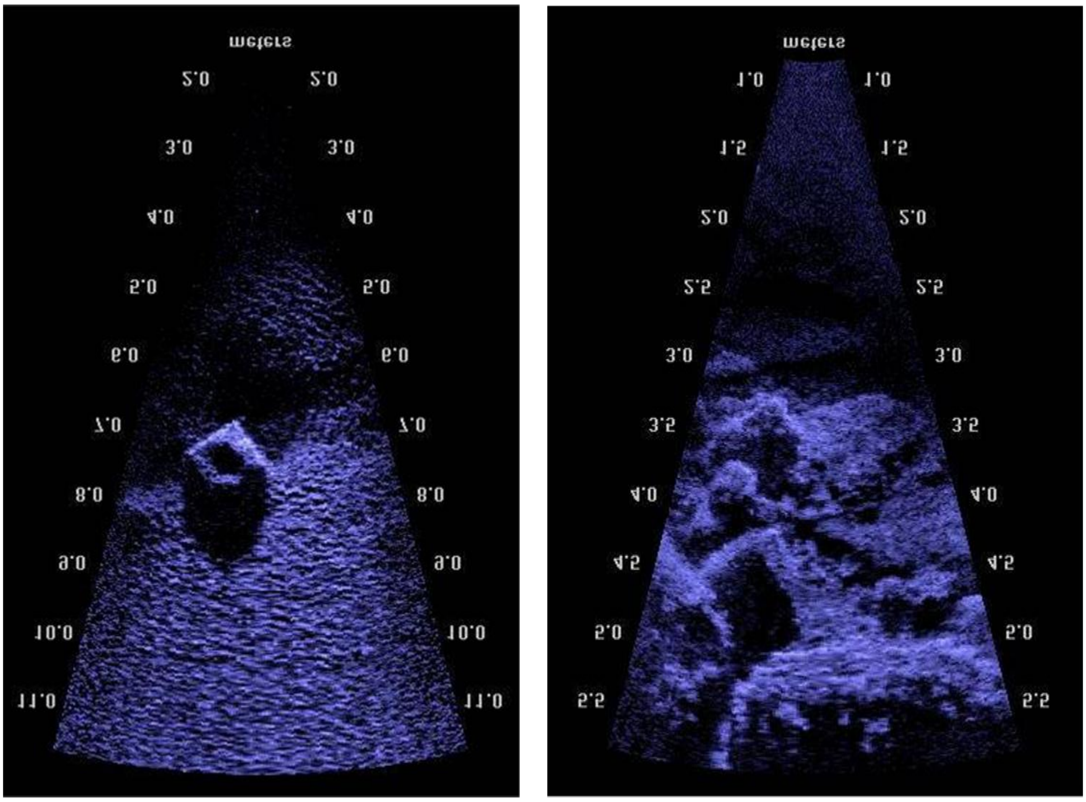


Figure 21 a) DIDSON-DH image of carved masonry block at St Katherine's site lying on the perimeter of a scour pit. Ripples again cover the site. **b)** Debris from St Peter's Church, at higher resolution (see scale) showing marine plant life on the surface of blocks and the random nature of the block field.

6.6.6 DIDSON avi files were reviewed and the best frames captured as screenshots using the DIDSON5.3 software (Appendix 3 Figures 3.1 – 3.4). These capture the range of DIDSON imaging from 1-5.5m, 2 – 11m and 5 – 23m. Further analysis of the DIDSON imaging data is discussed for each separate structure.

6.7 GEOPHYSICAL SURVEY SITE SCALE RESULTS

6.7.1 This section summaries the data for the main sites identified by the 2008, 2009, 2010 and 2012 surveys. Collectively they enable an evaluation of the site in terms of the type and scale of the remains and the sediment dynamics at each site between the 2008 and 2012 MBES surveys. A series of figures are presented that show where possible a 3D rendering of the high resolution (2cm) 2012 MBES data, the clearest geophysical data, and a difference maps of a digital elevation model from the 2008 and 2012 MBES data.

6.8 St Peter's Church (Appendix 3, Figures 3.1A-H)

6.8.1 St Peter's church collapsed down the cliffs during storms around 1688 – 1702, which gives a time of submergence of 307-321 years. Between 1654 and 1690, the church was dismantled much like All Saints, and so what is visible on the seafloor are the ruins of ruins. The site lies some 337m from the present (2000 AD) cliff, to the north of St James Street at a depth of 8.2 metres and covers an area of approximately 934 m^2. The ruins lie in a scoured trough on bedrock (clay), across which mobile banks of fine sediment periodically encroach into the ruins. The site is composed of three main groups of ruins which are thought to broadly relate to the church building (nave, aisles and chancel) and the tower. The area to the north lies c. 24m (c.72ft) north of the main tower fragments. Although of similar scale to the tower height of All Saints Dunwich (c.70ft) and St Andrew's Walberswick (c.70ft), the blocks are large and lie in a discrete group further west than the larger fragments of tower at the west end of St Peter's. The Agas map shows a group of three buildings in this area that were associated with the market place. It is possible, that these ruins are from one of those buildings, which if proven to be the case might identify the Town Hall or Market Cross (lost 1680-1717).

6.8.2 The site is characterised by a series of blocks with concentrations of larger blocks at the western end of the site. The blocks vary in size up to 2.24m in length (based on the R2Sonic 2012 multibeam survey) and stand between 0.2- 0.8 m proud of the sea floor (confirmed by diver survey). Average block size is 1.10m by 0.87m, with a tendency to be symmetrical rather than elongated (Figure 22)

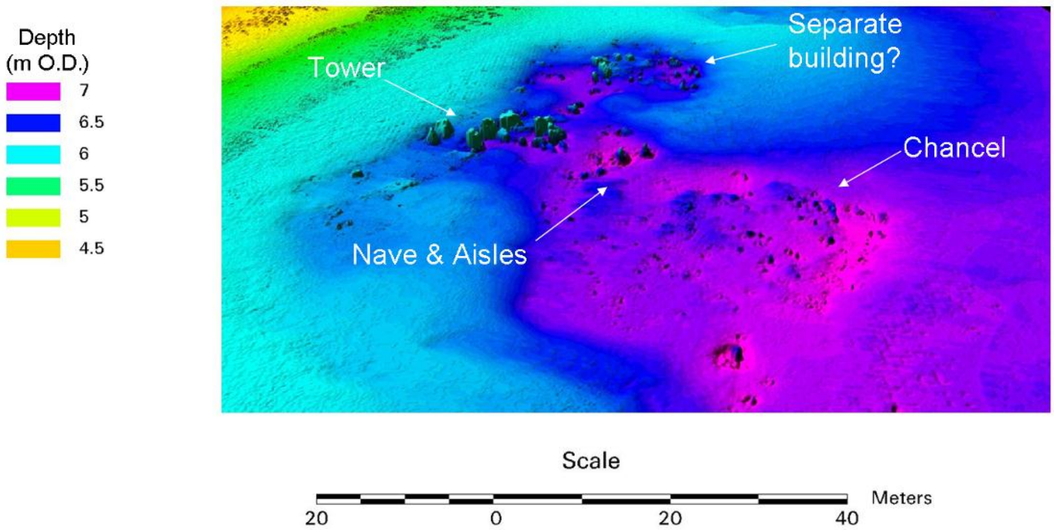


Figure 22 3D visualisation of the St Peter's church site. Different areas of ruins are shown, including the possible position of a separate building(s).

6.8.3 Diver surveys confirmed the presence of flint and mortar blocks of similar dimensions (estimated) to those measured from the Sidescan and swath bathymetry. During the 2008 survey, a sample of five stones was recovered from this site, all of which were large flints. None showed traces of mortar. The sea floor around the blocks at the St Peter's site is covered in large flints and stones that have fallen out of the walls presumably as the lime mortar dissolves over time. Recent underwater filming during a rare period of good visibility has revealed evidence of worked stones at the site, and the complete encrustation of the wall and tower fragments with sponges, highlighting the ecological value of the ruins in an otherwise sand covered seafloor (Sear et al., 2011).

6.8.4 Additional artefacts recovered from the site in 2009 by HWR include part of a mortar, a fragment of a stone coffin, and a large piece of oak planking of unknown origin. In 2008 divers recovered the nose cone of a phosphorous bomb dating from WWI or WWII. This may account for the magnetic anomalies found at the site in 2009 and 2012. Additional artefacts from the site were recovered by Stuart Bacon and divers over the period 1973-1988. These are recorded by Suffolk Underwater Studies (SUS). Some form part of the Dunwich museum collection, others are held by SUS.

6.8.5 Figure 23 illustrates how the area of the ruins has lost sediment relative to the 2008 MBES survey, and has formed scour pits around the larger blocks. To the west (landward) and adjacent to the site on the northeast, fine sediment has accumulated up to depths of 1.3m. This may mark a period of sedimentation resulting from the continued shoreward widening of the Dunwich bank.

6.8.6 DIDSON image captures from the avi files provide additional and higher resolution data (Appendix 3 Figures 1A-H). These confirm the presence of large mortar and rubble blocks. The uneven surfaces of the latter show evidence of the cobbles and boulders that make up the blocks, which is characteristic of the building materials used in Suffolk. The marine life seen in film footage shot on the site in 2009 is also evident in the DIDSON acoustic imaging.

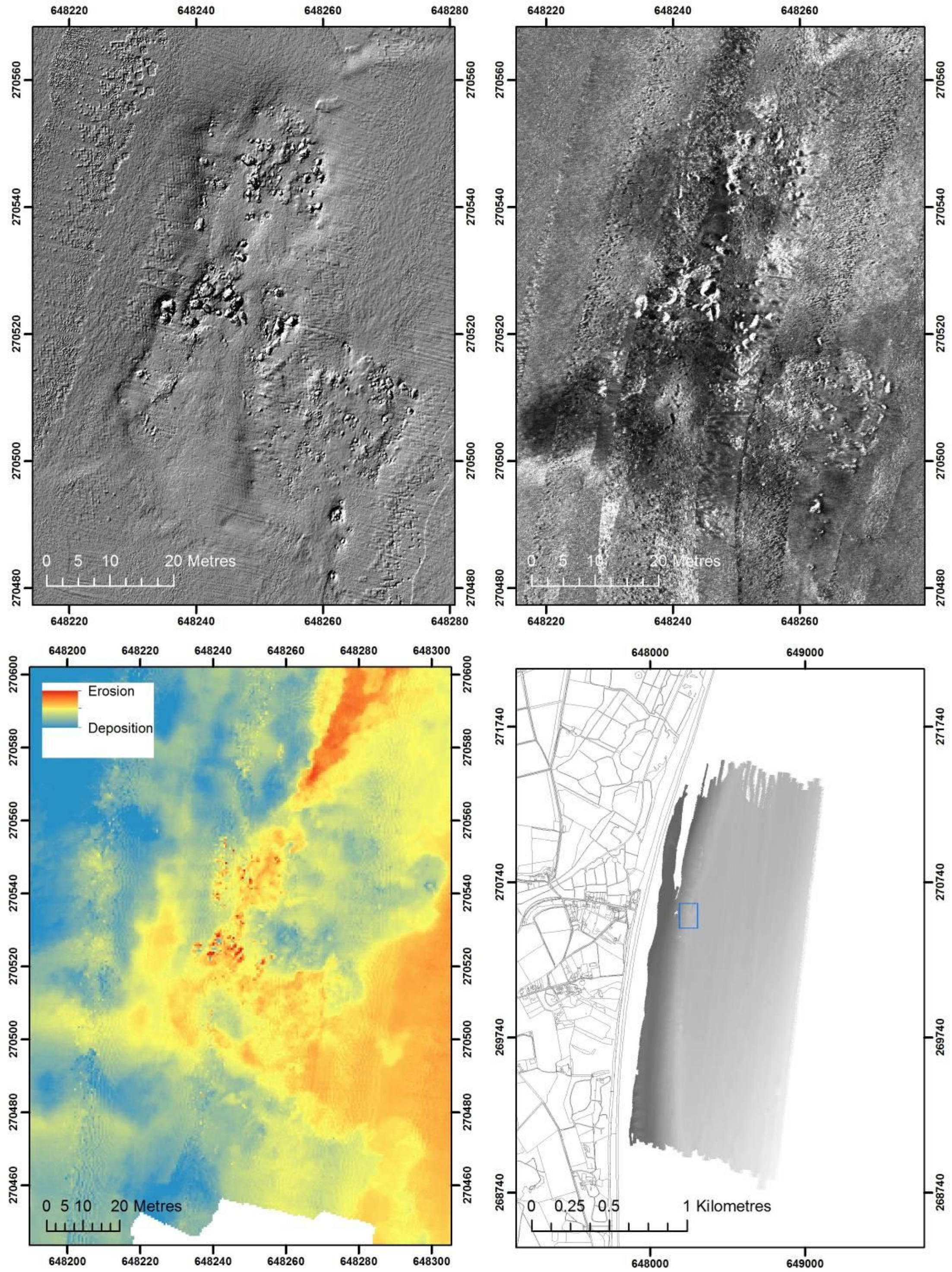


Figure 23 St Peter's Church. Top left – 2012 Multibeam at 5cm resolution. Top Right 2012 Sidescan Sonar at 2cm resolution. Bottom left shows the Bathymetric change at the site between 208-2012. Erosion at the blocks is an artefact of the positional and resolution errors between surveys. Larger areas of sediment accumulation and erosion correspond with Sidescan images form 2009 and 2012. Bottom right shows location of the site.

6.8.7 The site is composed of large rubble blocks with smaller blocks, boulders and cobbles often accumulated in discrete patches, perhaps where a block has disintegrated during collapse or from in-situ weathering/attrition whilst in the littoral environment. The seabed is a mixed of sandy and bedrock surface on which the ruins lie. There is no clear structure or morphology to the debris when visualised with the DIDSON.

6.8.8 Figure 24 illustrates the improvement in the resolution of data and the visualisation of the site using the DIDSON-DH compared to the highest resolution MBES and Sidescan data. MBES data presents a smoother surface to features and fails to capture the smaller blocks and boulders compared with the DIDSOn and Sidescan data. Didson image captures finer details of block surfaces and seabed, but looses information due to acoustic shadows.

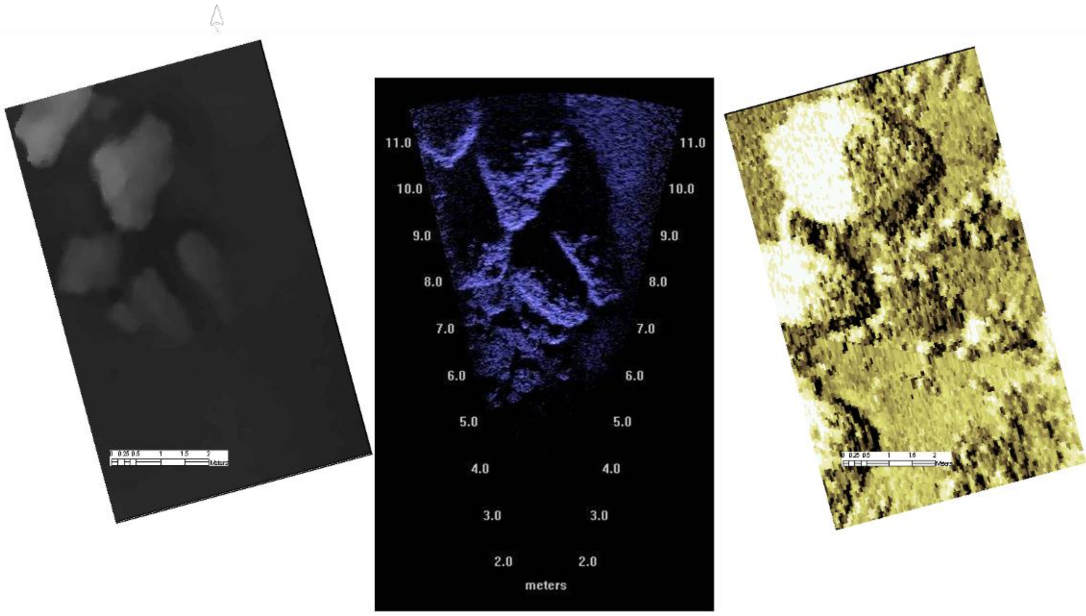


Figure 24 Intercomparison of R2Sonic multibeam sampled at at 5cm resolution (left), DIDSON-DH image with 2cm resolution and Klien3900 Sidescan data with 5cm resolution (right). Sidescan data suffers from large acoustic shadows, and failure to insonify some of the block edges. However, the Sidescan data does pick out the smaller blocks and boulders compared to the MBES. MBES data does not show roughness of block surfaces.

6.9 ST PETERS CHURCH NEW SITE

6.9.1 The 2012 Sidescan sonar survey data revealed the location of a new group of ruins, southeast of the St Peter's church site. Unfortunately, the MBES data from 2012 falls just short of the ruins so that only the Sidescan data coves the entire site (Figure 25). Differencing of the MBES data reveals that the site has been uncovered by net erosion of fine sediment across the site since 2008, though the blocks appear to be partly buried.

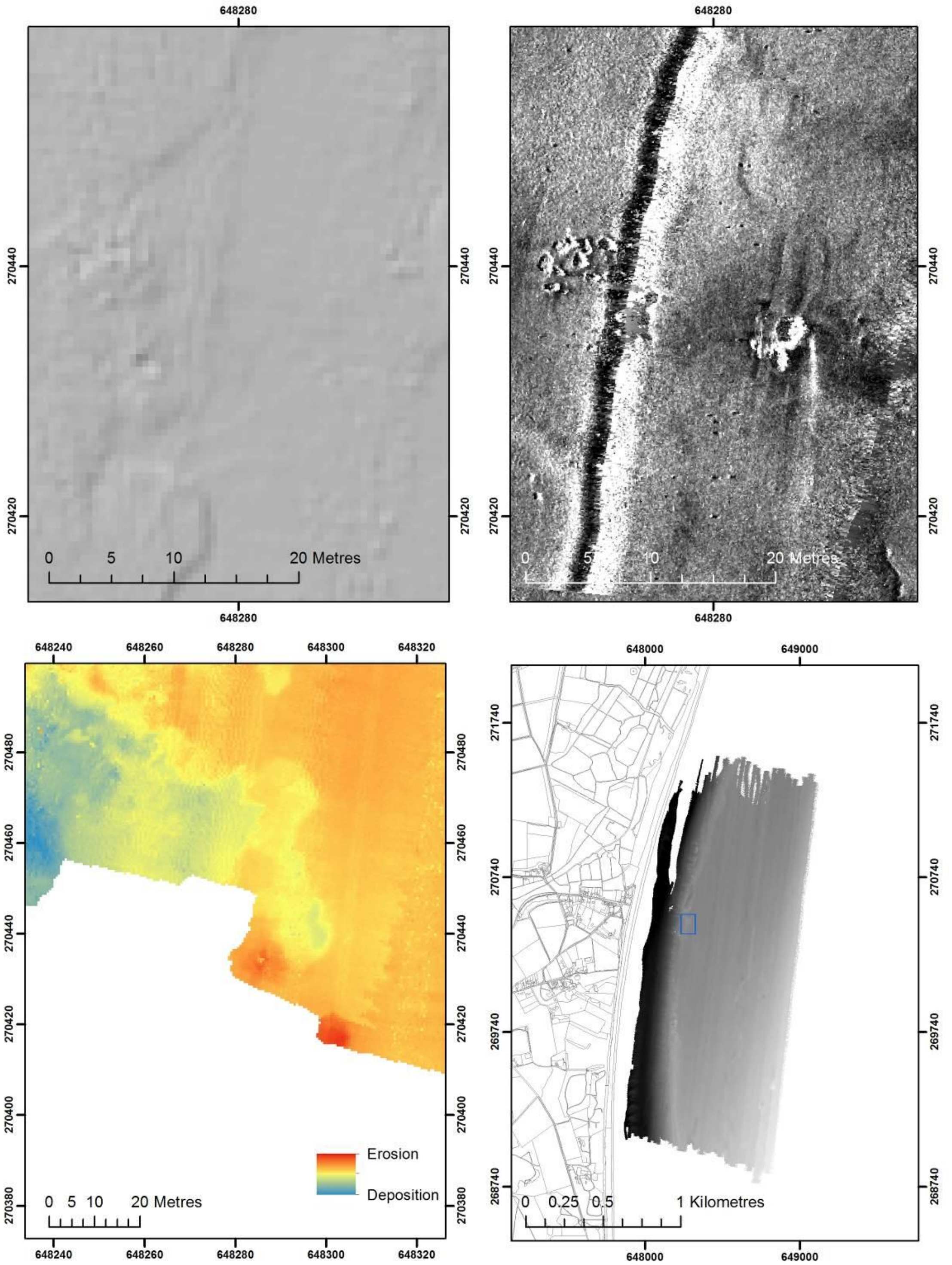


Figure 25 St Peter's Church New site. Top left – 2012 Multibeam at 5cm resolution. Top Right 2012 Sidescan Sonar at 2cm resolution. Bottom left shows the Bathymetric change at the site between 208-2012. Bottom right shows location of the site. Erosion since the 2008 surveys has revealed the ruins which exist in two clusters of blocks. No dives or DIDSON images are available.

6.9.2 The ruins form two groups, the eastern group is a tight cluster of 8-10 blocks, with scour pits around them covering an area of 33m^2. Block size averages 1.09m long by 0.66m in width, and are smaller than those found at other sites. The western group covers 24m2, and appears to be formed of a large block with "rats tails" of fine sediment to the south, and smaller blocks to the south and east of it. This western site is less confidently attributed to human origin.

6.9.3 The 2009 survey shows two blocks in a scour pit in the vicinity of the eastern site, otherwise the area was covered by fine sediment. The discovery of this site highlights the dynamic nature of the fine sediment, and how this affects the interpretation of the scale of marine heritage at Dunwich.

6.9.4 The sites lie in the vicinity of a group of large buildings shown on the Agas 1587 map. The town hall or Toll house might be in this area, and would probably have been partly constructed of stonework much the same as the Moot hall at Aldeburgh. This might explain the relatively small blocks and area occupied by the site.

6.9.5 No DIDSON or diver surveys have been undertaken to confirm the nature of the blocks.

6.10 St Nicholas Church

6.10.1 St Nicholas Church site is in close proximity to the assumed position of St Nicholas Church (Gardner 1754 records it as lying 20 rods (100m) SE of Blackfriars Monastery). The debris field lies 168m SSE of Blackfriars ruins, 746m south of St Peter's in the scoured area of seabed east of the inner sand bank. The ruins appear as scattered blocks of masonry in the multibeam images lying in an area of the sea floor that is lower than the surrounding bed (Figure 26). The site lies some 410 m east from the present (2000 AD) cliff line, at a depth of 8.4 metres and covers an area of approximately 630 m^2. The debris field is symmetrical with no clear western accumulation of larger blocks. This is in accordance with the description of the church as a cruciform structure with a central tower. St Nicholas church is reported to have probably collapsed over the cliffs sometime in the late 15th Century (c.1480 A.D. Gardner 1754) which would give the ruins an approximate time of submergence under the sea of 529 years. However, the reconstruction of cliff retreat, coupled with the position of the ruins, supports the view that the ruins have been on the seabed since c. 1700, which reduces the period of submergence to 332-360 years; a similar time to the ruins of St Peter's. The church was ruined and stripped of the most valuable materials (wood, lead, bells). Thus the remains are those of a ruined structure that collapsed down a cliff (height of cliff c. 19m based on reconstructed topography). The lack of a building on this area on the Agas map may point to it being nothing more than the foundations of the former church.

6.10.2 Diver surveys were conducted at this site in 2008 and resulted in recovery of four stones that were adjacent to larger structural blocks. Three of these stones were geologically erratic to the area, being a pink granite, a basalt, and a schist. The other was a large un-worked flint. Two of these erratic blocks contained traces of what appeared to be a lime mortar adhered to their surface. Blind analysis of a sample of this mortar and a sample of mortar recovered from inside a collapsed section of the southern wall of Greyfriars monastery, was undertaken for English Heritage by Sandberg LLP (report 39360/C). This confirmed the sample recovered from the submerged site as feebly hydraulic lime mortar of identical composition to that of the Greyfriars monastery sample. Hence the structures on the seafloor are confidently ascribed to human origin and most likely to be part of St Nicholas Church. Diver surveys undertaken in 2008 in poor visibility confirmed the presence of relatively large blocks of flint and rubble scattered over the site, and the possible presence of some worked stone material. The diver survey also provided independent estimates of the block sizes as approximately 1.4m length and between 03-0.6m height above seabed. The Klein 3900 sidescan survey in 2009 (Figure 27), gave an average block size of 1.3m length by 0.90m width, whereas the higher resolution MBES survey of 2012 record them as larger at 1.72 x 1.10m as a result of the burial o the smaller blocks visible in the earlier survey. The 2008 and 2012 multibeam survey give a block height above seabed of between 0.3-0.8m, similar to those reported at the St Peter's and All Saints sites (Bacon & Bacon 1979; 1988).

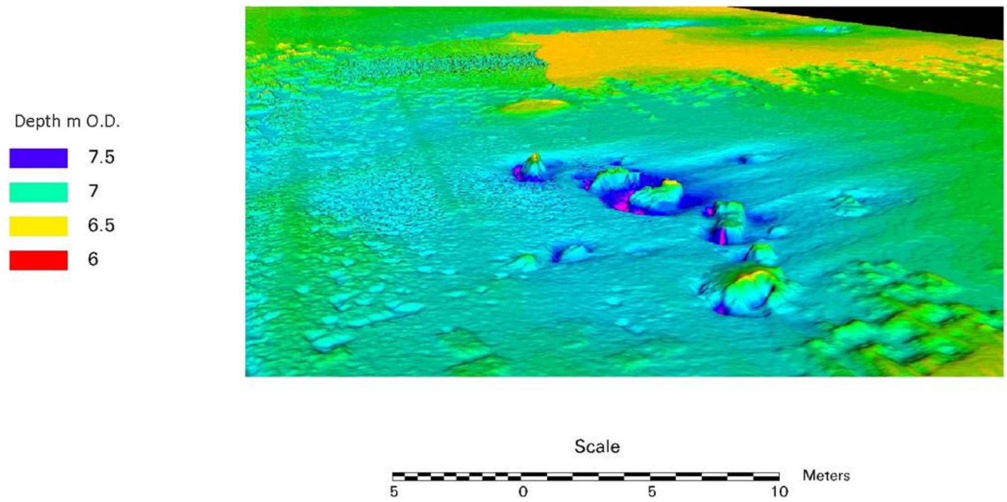


Figure 26 St Nicholas Church site is a discrete collection of large blocks with some additional structure of smaller size in the area to the west. In the 2012 bathymetric survey much of the site had been covered by fine sediments – though scours processes round the blocks prevents them from being completely buried.

6.10.3 The Sediment dynamics at the site shown in Figure 27, demonstrate net accumulation of fine sediments around the site since 2008. This is confirmed by the Sidescan and MBES survey data that show scour pits and "rats tails" of fine sediment around the larger blocks. There is not sign of the smaller blocks visible in the 2009 and 2008 surveys data nr the seabed scour feature. This site is therefore being buried by fine sediments, most likely as a result of the erosion of fine sediments widening of the Dunwich bank shorewards, but also due to material being supplied from the erosion shown to the north.

6.10.4 DIDSON images (Appendix 3 Figures 2A-L) reveal evidence for rubble and mortar blocks, surrounded by stones and block fragments and boulders. Larger blocks have flat sides and squared corners indicative of human origins. Some areas of smaller blocks/boulders perhaps mark remains of blocks that disintegrated during collapse. There is no structure or form to the debris field to suggest the original origin of the building. No carved stone is evident in these images. The seabed around the site at the time of imaging in 2010 was largely devoid of rippled sand, unlike the later (2012) MBES images.

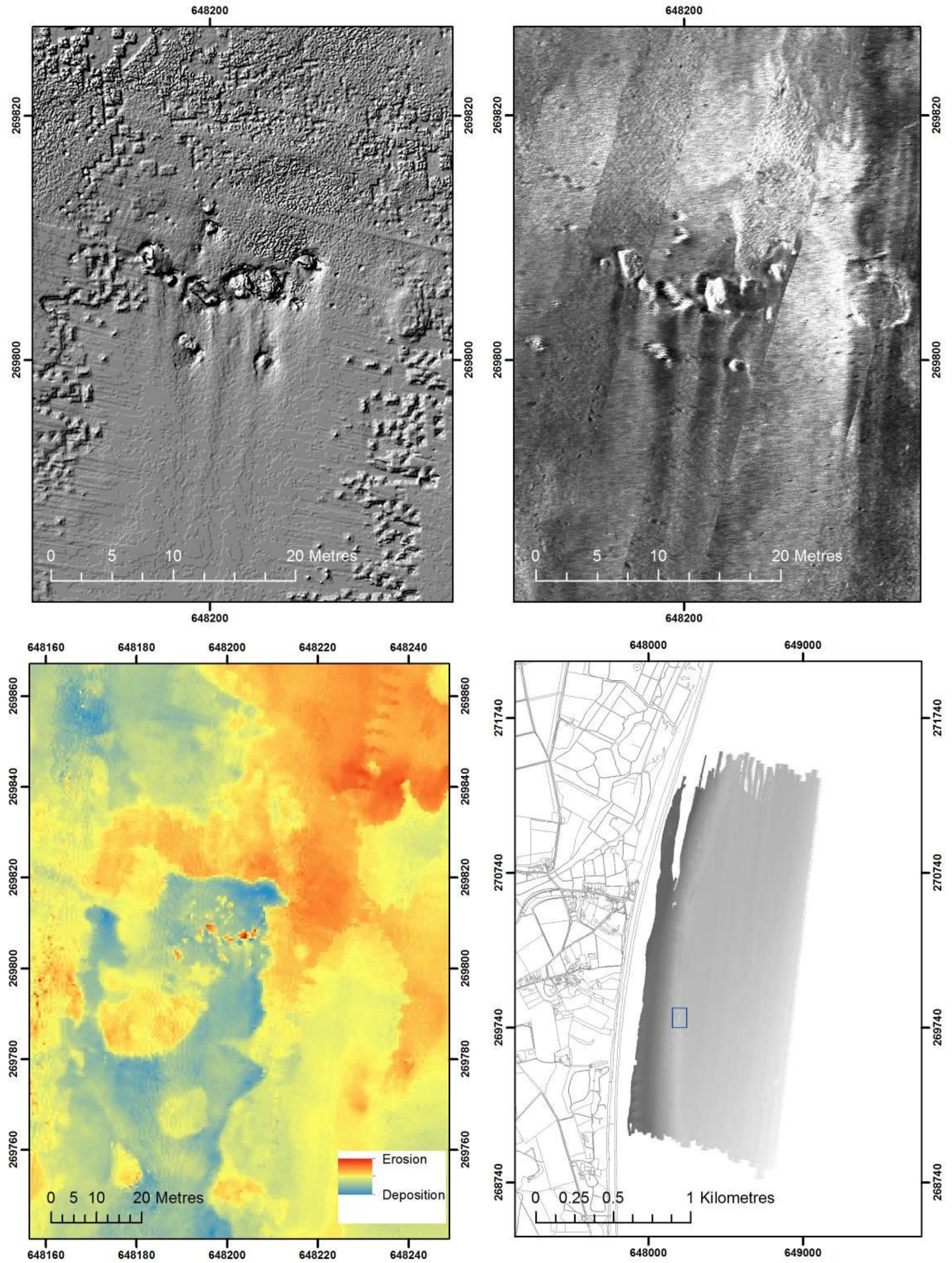


Figure 27 Visualisation of the St Nicholas church site showing evidence of sediment accumulation over the site, and scour to the north and east. MBES and Sidescan show how the ruins interact with the flow and sediment to create scour pits and tails to the south.

6.11 BLACKFRIARS FRIARY

6.11.1 Blackfriars site covers and area of 1643m^2, and contains two areas of larger structure, and a field of smaller debris to the east. The site was poorly visualized in the 2008 swath bathymetry and Klein 3000 sidescan sonar survey. However the Wessex Archaeology Klein 3900 sidescan survey and 2012 Sidescan and Multibeam surveys revealed more detail (Figure 28, Figure 29). The site differs from all other targets in the absence of large block fields. Instead there are two areas where larger blocks (4.3 x 2.9m) project 0.4m above the sea floor, a more subdued area of seafloor relief to the east of these blocks (possible burial by fines) and an area of relatively high intensity isonification return that appears to result from a strew of smaller blocks (<0.3m x 0.3m). Interpretation is made more complicated by the outcropping of bedrock at the site, which results in block-like structures.

6.11.2 The Agas map records Blackfriars as an overgrown ruin similar to that of the current Greyfriars monastery. No tower is shown in the illustration although other friaries of the Dominican's have central towers. Large masonry structure is present and has resulted in blocks similar in scale to those found at the other sites with towers.

6.11.3 The DIDSON images (Appendix 3 Figures 3A & B) show what appear to be irregular blocks of probable geological origin emerging from a rippled sandy bed. The diffuse nature of the ruins at this site makes it difficult to survey. Further survey is needed to confirm the presence of building materials.

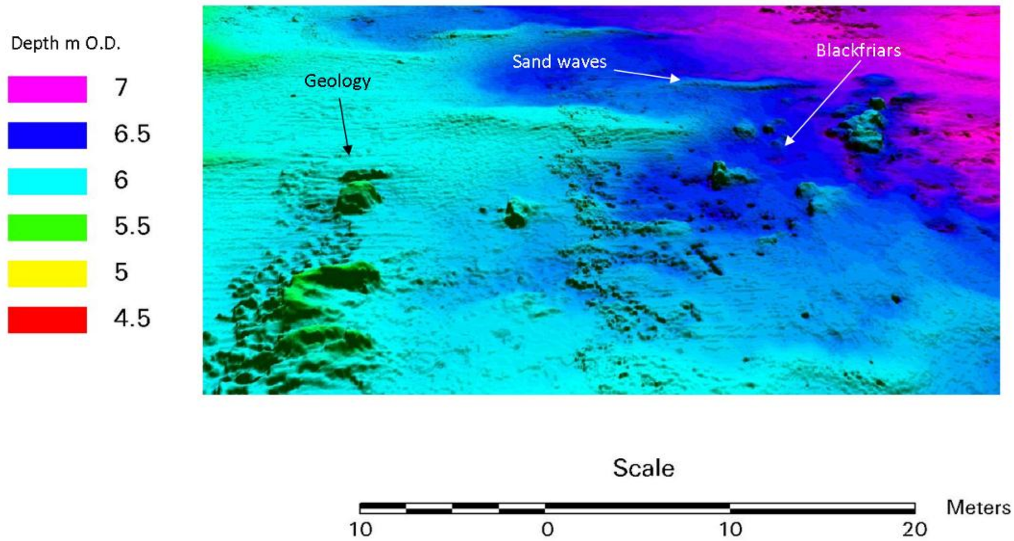


Figure 28 Blackfriars Friary is a more diffuse site where much of the structure is in the form of areas of large cobbles and stones. Some larger blocks from buildings are visible. Despite DIDSON-DH survey, it is still not clear that this site is of human origin.

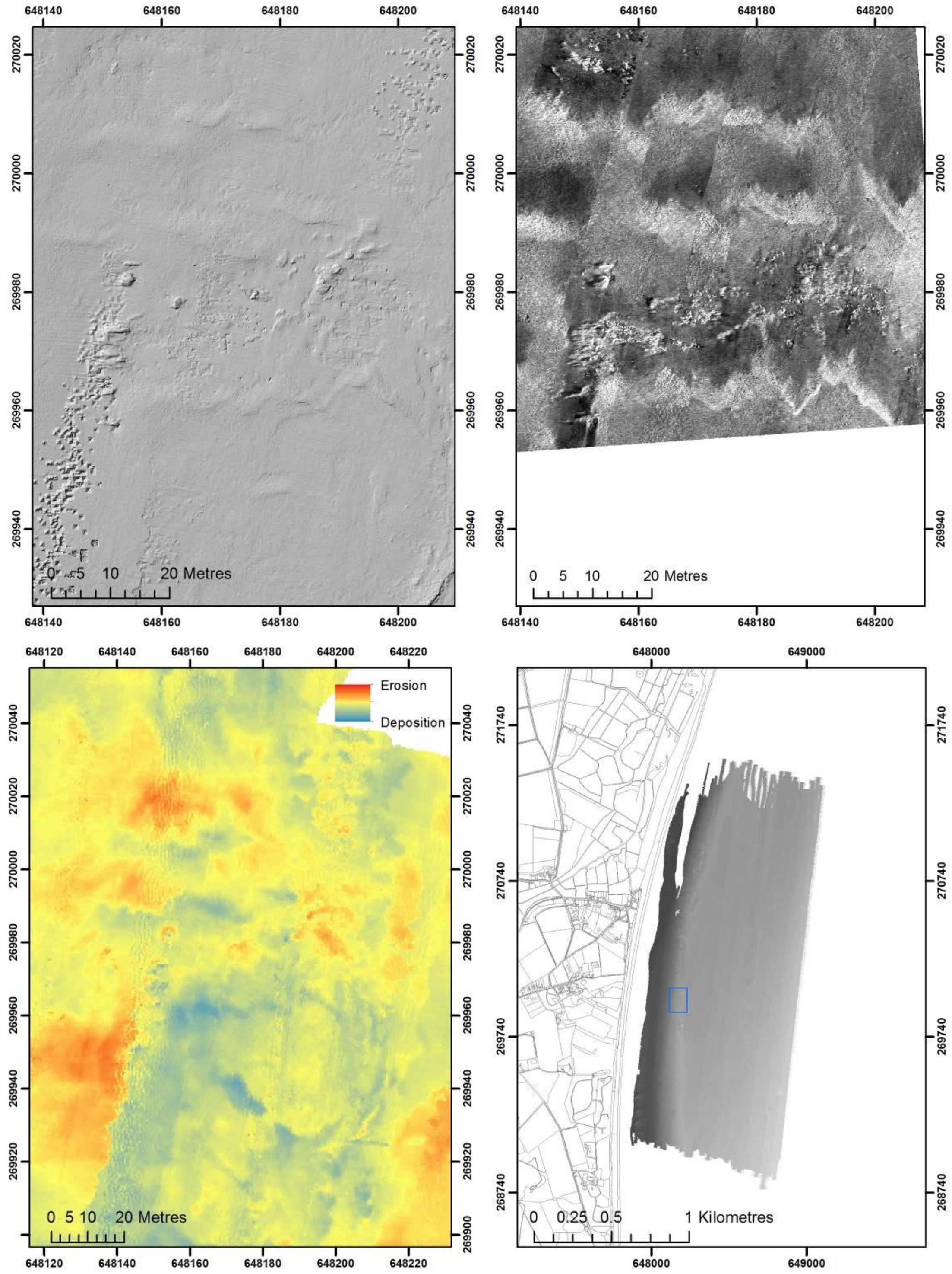


Figure 29 Visualisation of Blackfriars site showing the area of isolated large blocks and smaller debris field to the east. The area shows horizontal areas of sediment accumulation and erosion that result from the passage of sand waves.

6.12 BLACKFRIARS NEW

6.12.1 Occupies and area of 208m^2 composed of a larger central block surrounded by what look like groups of smaller blocks (Figure 30). The site has been revealed by the migration of sand waves; the site itself is currently partly buried by a sand wave to the south. The site has not been explored by diver surveys and as such we are uncertain as to its human origin. If it is human in origin, then It is most likely to be one of the outbuildings of the Dominican Friary.

6.12.2 There is no DIDSON imagery from this site or diver surveys.

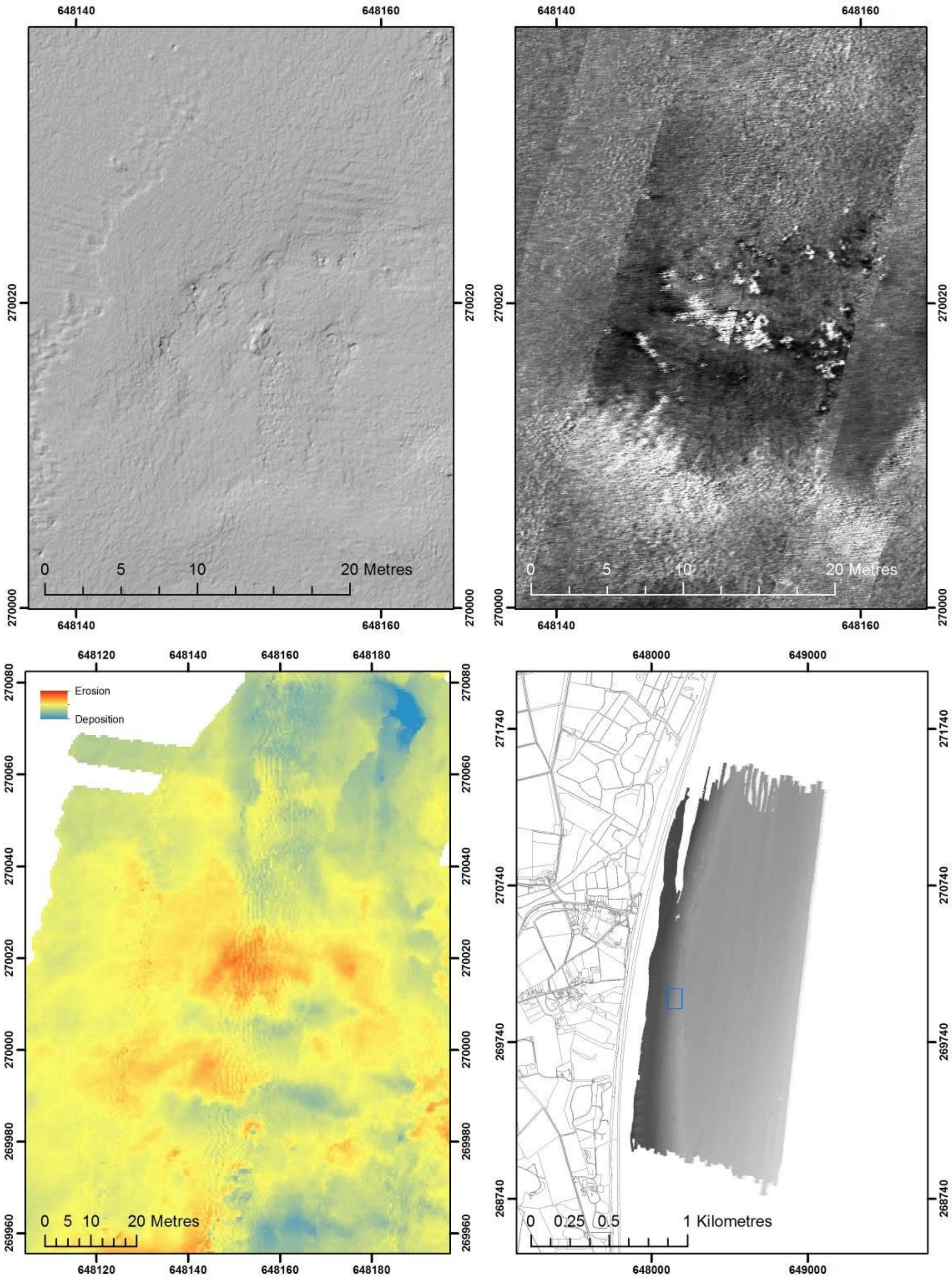


Figure 30 Blackfriars new site. Located to the north east of the Blackfriars ruins, the site was exposed by the migration of sand waves over the site (blue sinuous features in bottom left figure). The site is still partly buried, but appears as a larger central block with smaller block fields around it.

6.13 St Katherine's Chapel Evaluation

6.13.1 The possible site of St Katherine's Chapel covers an area of 183m^2, containing a discrete debris field composed of relatively small masonry rubble blocks (1.91 length:width ratio) that average 1.54m by 0.84m, with a swath bathymetry derived height of 0.3-0.6m (2012 MBES), (Figure 31 and 32). The vicinity of the target is associated with a single unidentified building on the 1587 Ralph Agas map. It lies north of the centre of the town, 226m NNE of the ruins of St Peter's church, and 600m south of the harbour. The small area of the debris field, combined with the relatively discrete blocks and debris field are most like the new site identified south of St Peter's church, which we interpret to reflect a smaller chapel site rather than another church. Size analysis of the 10 largest blocks at each site, reveals that this site is composed of smaller blocks, and is statistically different to the other Church sites (t-test, P<0.001), but not significantly different to the St Peter's New site.

6.13.2 Bacon (1982; 1988) reports finding carved imposts and other worked masonry from a site that fits the location of this structure. The recovered materials strongly support an ecclesiastical origin, though none of the DIDSON or multibean data can confirm this. Bacon (1982) associates it with the chapel of the Maison Dieu, based on the location recorded in the Hamlet Watling 1858 map. However, Sear et al 2011; 2008) has cast significant doubt on the validity of this map as a representation of pre-1587 Dunwich. Moreover, the location relative to the position of the Maison Dieu shown on the Agas map of 1587, strongly suggests that it is not associated with this house. At present therefore this structure remains unidentified, though it was clearly present as a building in 1587. Its vicinity to St Johns raise the possibility of it being St Katherine's Chapel. It is reported to have been lost around the same time as St Johns Church (c.1550+, Gardener 1754), but coastal retreat analysis puts it as later (c. 1650). Further investigation of the site is required in order to confirm its origin and to identify the status of the building.

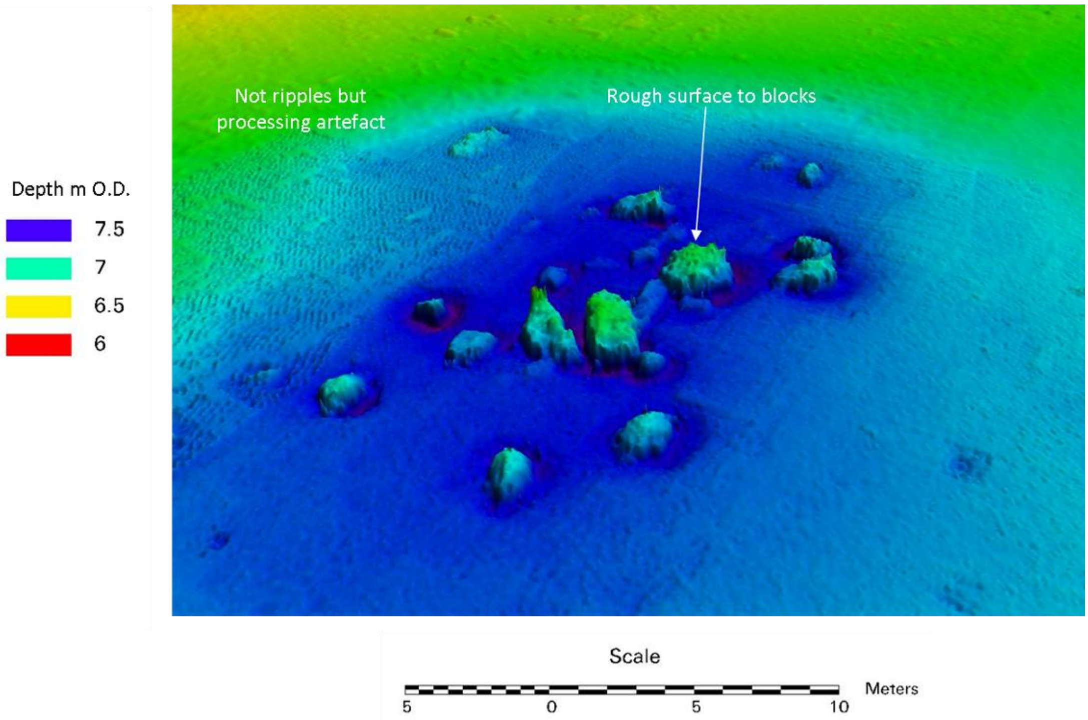


Figure 31 St Katherine's chapel site is a series of discrete blocks covering a relatively small area compared to the other sites. The high resolution MBES picks up the rough surface of the rubble masonry and the scour pits around the blocks. The smaller debris from the site is not evident, but is largely because of sand deposition over the site since the 2010 DIDSON and 2009 Sidescan data was captured.

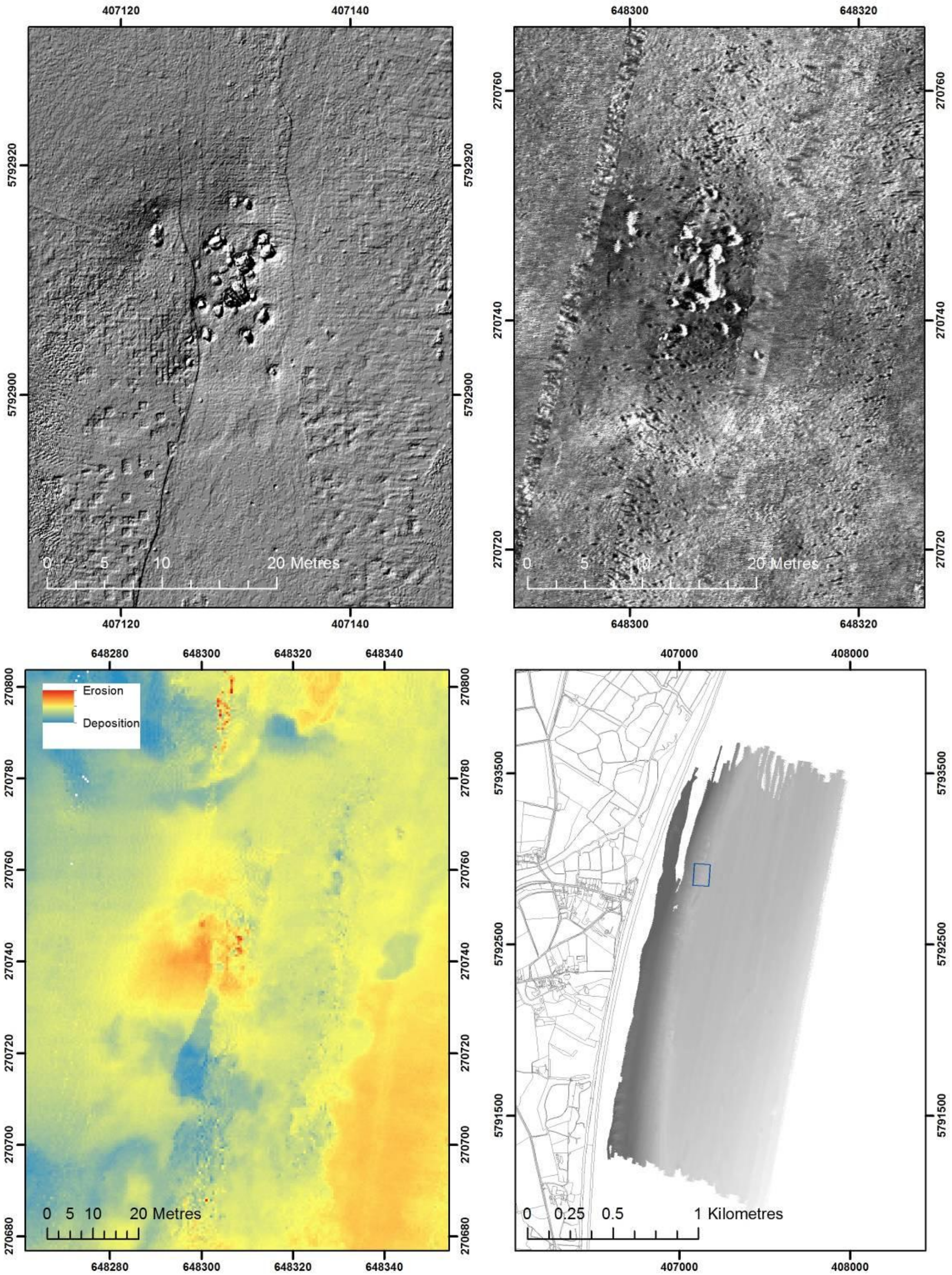


Figure 32 shows that the site has been subject to net removal of fine sediments since 2008, and the formation of scour pits around the larger blocks. The trapezium shaped area of net fine sediment accumulation south of the ruins is an artefact of the bathymetric processing. Accumulation of sediment is occurring shoreward's as in the other sites, and may be due to widening of the inner sediment bank.

6.14 Evaluation of the application of different geophysical techniques for site scale investigation at Dunwich Town site.

6.14.1 In the 2012 survey, the St Katherine's site was surveyed using the DIDSON-DH. This permitted an evaluation of the different geophysical technologies for investigation of the ruins of stone and rubble structures. The evaluation was based on an analysis of the number and dimensions of the blocks identified in each dataset defined by area, perimeter, maximum width and maximum length of each block as a basis for the comparison. All blocks were digitized in ARCMAP 10.1 at the same scale (Appendix 3, Figures 3.5 – 3.7). All blocks were used in the analysis, which resulted in an unbalanced dataset. A Mann-Whitney U-Test was used to test for population difference since the data were not normally distributed and were not amenable to transformation. A threshold power of $P \le 0.05$ was set for each test. The Sidescan Sonar data from 2008 was of insufficient resolution to identify individual blocks, and was discarded from the analysis.

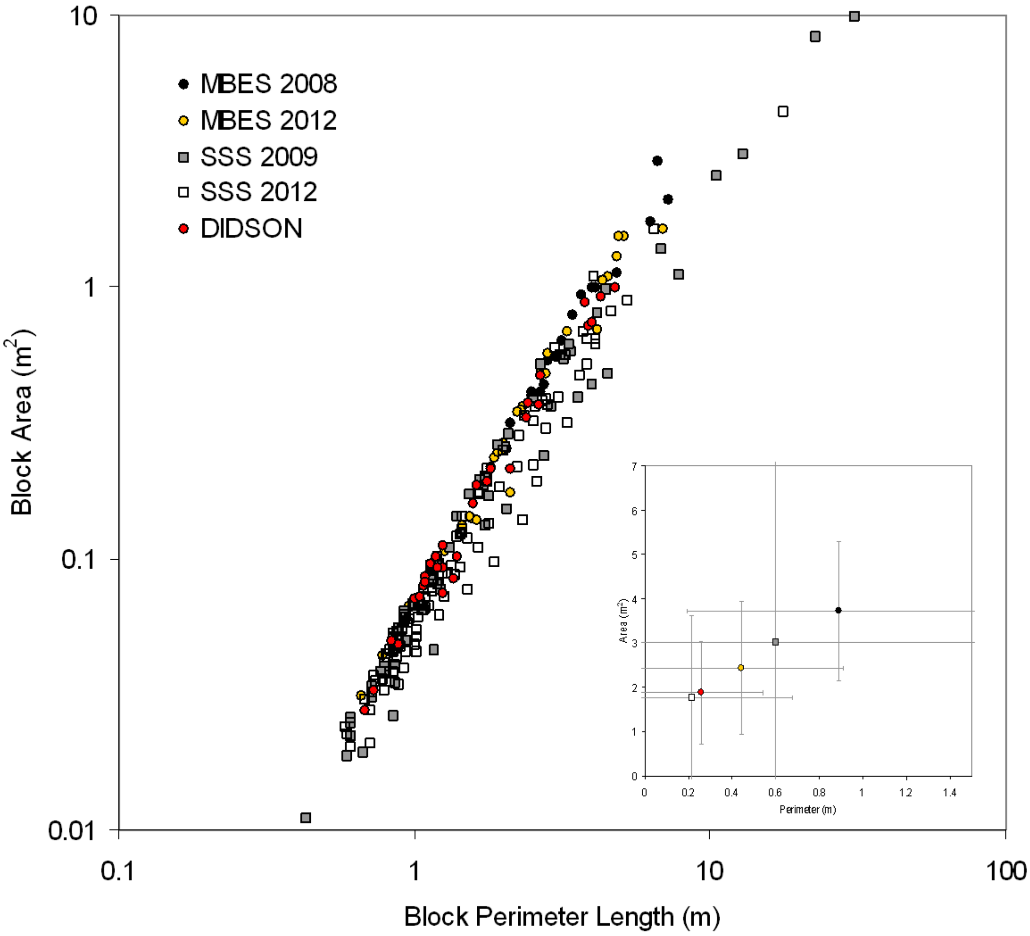


Figure 33 Comparison of block area and perimeter derived using different geophysical technology. Inset graph shows the average values and standard deviations. The 2012 MBES and DIDSON data capture fewer, larger blocks compared to the lower resolution 2008 MBES and the Sidescan data.

6.14.2 Our Null hypothesis was that there would be no difference between the population of blocks in each geophysical survey.

6.14.3 Unsurprisingly there is a strong correlation between the dimensional measures (area and perimeter length Figure 32). However, the differences between survey techniques are significant. Table 5 summarises the results for the different surveys. These demonstrate that for the same site, the survey technology and deployment can result in significantly different results. In some cases the difference is dependant on the data resolution; for example the MBES survey in 2008 resulted in identification of fewer larger blocks (Table 5, Figure 33). In other cases it reflects the technology (Bates et al., 2011). The application of sidescan sonar and DIDSON in the shallow depths (<8m) over the site created low beam angles. As a result, there was data loss from acoustic shadowing despite high resolution imaging. For example, the 2012 Sidescan and DIDSON surveys both identified either more and/or smaller blocks compared with the 2012 MBES survey (Table 5). The acoustic shadows in effect reduce the block dimensions by obscuring the sides of the blocks within the shadows, whilst the higher resolution increases the number of smaller blocks visible.

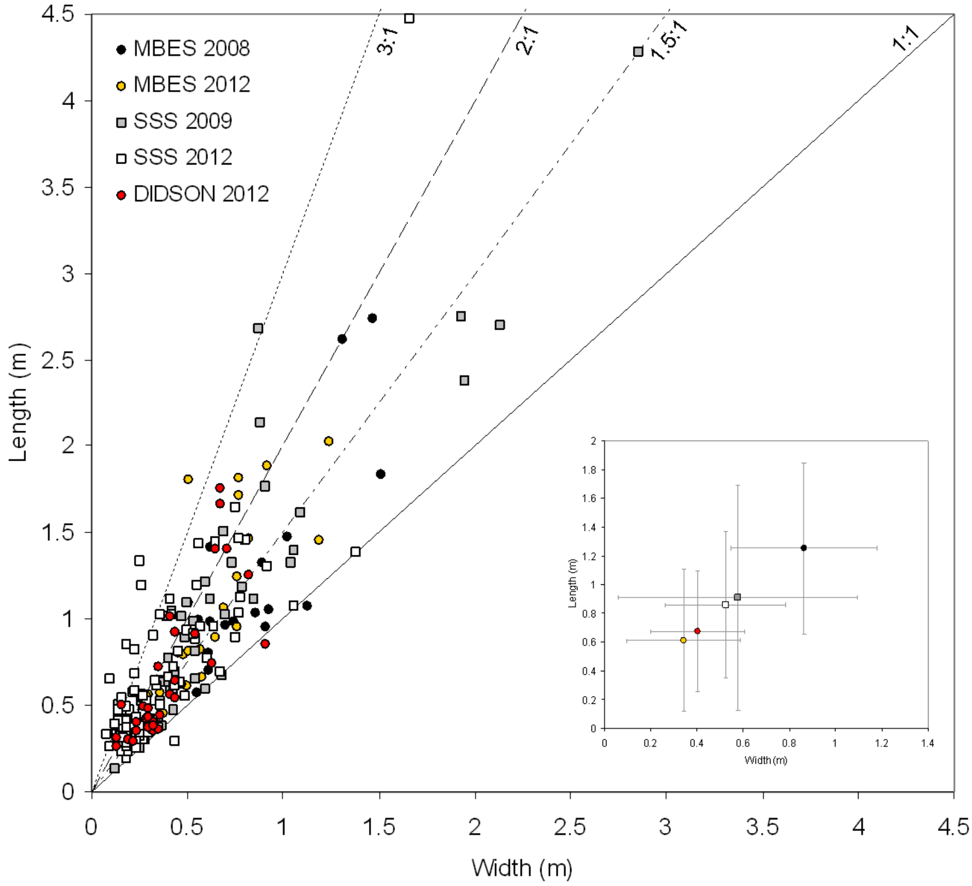


Figure 34 Comparison of block aspect ratio derived from five different geophysical surveys. Inset graph shows the average and standard deviations of the datasets. 2012 high resolution MBES and DIDSON data result in smaller numbers of smaller blocks compared to Sidescan data and low resolution MBES.

Survey metric	MBES 2008	MBES 2012	SSS 2009	SSS 2012	DIDSON 2012
Area of target surveyed	100%	100%	100%	100%	83%
Length	1.25, *0.6* SD: All other survey techniques. Blocks are larger.	0.86, *0.51* SD: MBES08, SSS12, DIDSON. NSD: SSS2009.	0.91, *0.78* SD: MBES08 NSD: MBES12, SSS12, DIDSON	0.61. *0.50* SD: MBES08, MBES12. NSD: SSS09, DIDSON.	0.67, *0.42* SD:MBES08. NSD: MBES12, SSS12, SSS09.
Width	0.86, *0.32* SD: All other survey techniques. Blocks are larger.	0.53, *0.26* SD: MBES08, SSS12. NSD: SSS09, DIDSON	0.58, *0.52* SD:MBES08, SSS12. NSD: MBES12, DIDSON	0.34, *0.25* SD: All other survey techniques.	0.40, *0.20* SD: MBES 08, MBES12, SSS12. NSD: SSS09.
Area	0.89, *0.70* SD: All other survey techniques. Blocks are larger.	0.44, *0.47* SD: All other survey techniques.	0.6, *1.67* SD: MBES08 NSD: MBES12, SSS12, DIDSON	0.22, *0.46* SD: MBES08, MBES12. NSD: SSS09, DIDSON.	0.26, *0.26* SD: MBES08, MBES12. NSD: SSS09, SSS12.
Perimeter	3.72, *1.56* SD: All other survey techniques. Blocks are larger.	2.44, *1.50* SD: MBES08, SSS12. NSD: SSS09, DIDSON	3.02, *5.05* SD:MBES08. NSD: MBES12, SSS12, DIDSON	1.77, *1.85* SD: MBES08, MBES12. NSD: SSS09, DIDSON.	1.88, *1.15* SD: MBES 08. NSD:MBES12, SSS09, SSS12.
No. Blocks Identified	18	34	59	117	31

Table 5: Results of Mann-Whitney U-Test comparison between block dimensions recorded using different geophysical survey technology. Differences are all significant at $P<0.05$. Although differences are introduced by the temporal dynamics of seabed, with more burial in 2012 compared to 2008 and 2009 surveys, there is no systematic bias (see Figures X & Y). Values in boxes are Mean and *Standard Deviation*. SD is a Significant Difference, NSD is No Significant Difference.

6.14.4 In contrast, the 2009 Sidescan sonar survey resulted in larger overall block sizes compared with the 2012 Sidescan, MBES and DIDSON surveys despite more blocks in the latter two surveys. Figures 3.5 and 3.6 (Appendix 3) shows how the acoustic shadowing in the Sidescan data in this instance, increases the apparent block dimensions.

6.14.5 The DIDSON georectificed images are of relatively poor quality compared with the 2012 and 2009 Sidescan and MBES. It was still possible to identify and digitize the outlines of the blocks. Nevertheless, the resulting images show the potential for this technology to map archaeology in zero-visibility, and to capture data that is similar to other conventional technology (e.g Sidescan Sonar 2012). Figures 3.7 and 3.8 (Appendix 3) also demonstrate the need for fixed, spatial reference points when using DIDSON in mapping mode.

6.14.6 High resolution multipass MBES data (2012 survey) is able to be visualised in 3D, which is a powerful technique for understanding site conditions and context. However, the data appears to under-represent the smaller blocks and does not visualize the sand ripples visible in DIDSON and Sidescan data, despite a 5cm resolution. Overall block dimensions are larger than DIDSON and Sidescan datasets, the latter reflecting the lack of smaller data. MBES data does not suffer from acoustic shadowing to the same extent as Sidescan or DIDSON. The results of multipass MBES data are considered to provide reliable estimates of block dimensions but with errors of c.7cm.

6.14.7 In order to reduce the bias resulting from increased sample size and reduced block dimensions, we repeated the analysis using the 10 largest blocks in each survey dataset. The same blocks were identified between surveys.

6.14.8 The results showed that MBES08 is not significantly different across all metrics to MBES 12 and SSS12, but is different to DIDSON (width) and all metrics in SSS09. MBES12 is significantly different to Sidescan data collected in 2009 and DIDSON data collected in 2012, but is no different to SSS12 data. SSS09 data is significantly different to all other datasets. DIDSON data is significantly different to SSS09, and MBES12, but not SSS12.

6.14.9 Figure 34 presents the sample means for length and width of the 10 blocks. What is apparent is the consistency of aspect ratio between the different technologies, with the exception of the lower resolution MBES08 data. The effects of the acoustic shadowing in 2009 results in smaller overall values for both length and width. A similar problem arises with DIDSON data. The Sidescan data from 2012 reflects the shadowing as higher standard deviations despite the smaller sample size.

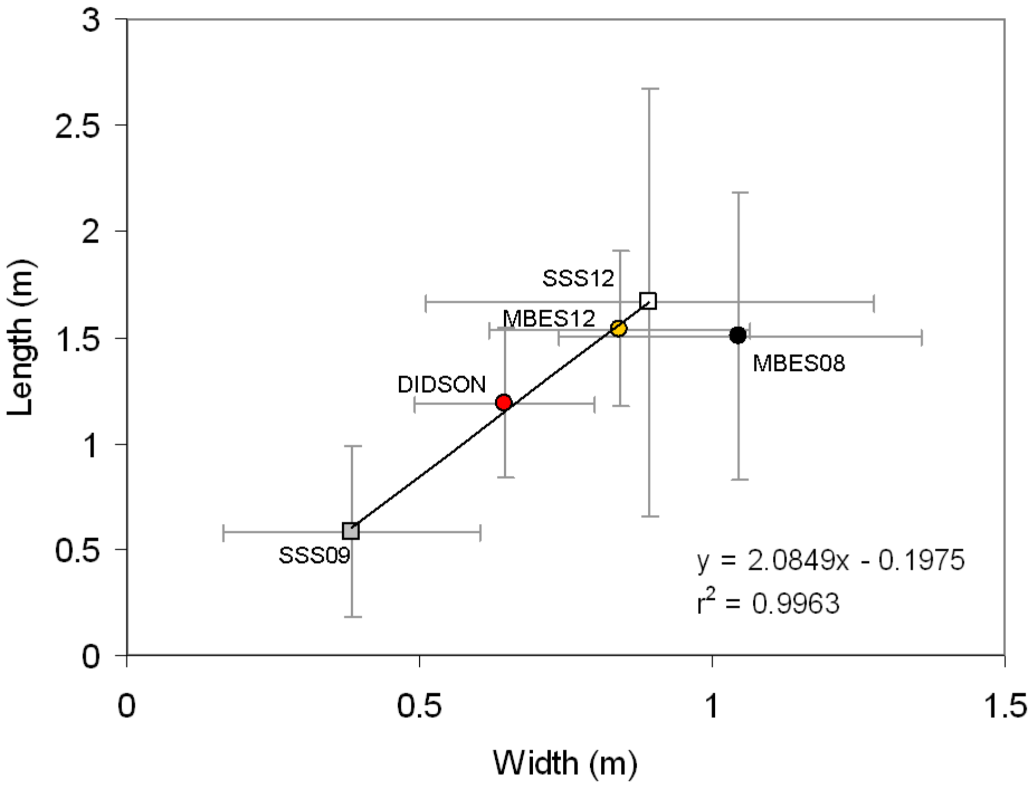


Figure 35 Sample means and standard deviations for 10 largest blocks. Note consistent aspect ratio (L/W = 2.09) between geophysical surveys with the exception of the lower resolution MBES08 data. Acoustic shadowing reduces block dimensions (SSS09, DIDSON) or increases variability in the measurements (SSS12).

6.15 SUMMARY EVALUATION

6.15.1 A new conclusion based on this report, is that all the ruins identified on the seabed have experienced a similar history and length of time within the littoral environment. Each structure, with the possible exception of the St Katherine's chapel site for which historical information is lacking, underwent a period of closure and stripping of materials considered valuable at the time. This ranged from 41 years in the case of St Peter's church to 320 years in the case of St Nicholas church (Table 6). Each building collapsed in a ruined state, down a cliff of between 14 – 19m in height during storms, and entered the beach zone. The longevity of time exposed to beach processes is unknown, but was probably of the order of 50 – 100 years depending on the rate of cliff retreat and beach elevation. Thereafter, the ruins were subject to periods of burial under fine sediments, and re-exposure depending on the dynamics of offshore sandbanks. The period of time each ruin has been in the littoral zone is quite similar, averaging 334 ± 29 years. The main difference appears to be the time period each building spent between closure and loss over the cliff. In the case of St Nicholas Church this time is much longer than St Peter's church, which might explain the more extensive ruins of the latter. Similarly, Blackfriars ruins are less extensive than any of the other sites, which might reflect the extended period over which the site was in ruins and subject to robbing much as the current Greyfriars site has experienced.

6.15.2 We make the hypothesis that the extent of the archaeology on the seabed reflects the state of the ruins before they were lost to cliff erosion. We also alter the previous hypothesis of Sear et al (2011) regarding the state of the St Katherine's chapel ruins. Previously we understood these to be more extensive (longer more intact blocks of masonry) and hypothesized from this that the building had collapsed over a lower cliff compared to the other sites. Topographic reconstruction refutes this hypothesis; moreover, the high resolution MBES surveys of 2012 shows the blocks to be smaller in scale relative to other sites (Figure 35); the previous interpretation being an artefact of the available data in 2008/2009.

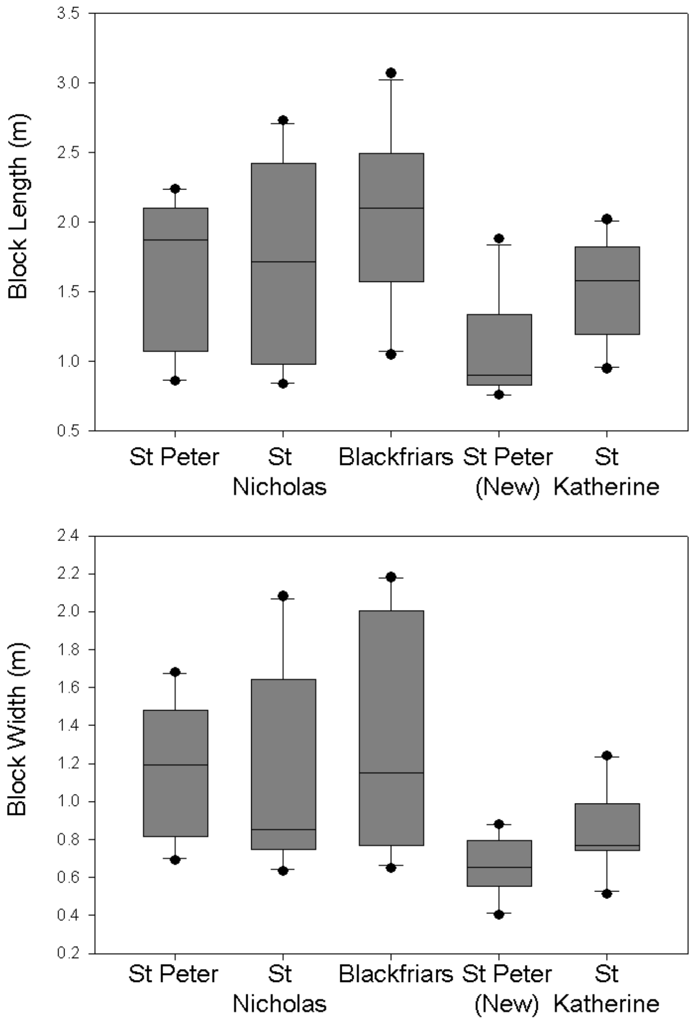


Figure 36 Comparison of the largest 10 blocks measured from 2012 MBES swath bathymetry, and in the case of the new site at St Peter's, 2012 Sidescan Sonar. The new site and St Katherine's chapel site reveal that the largest blocks are much smaller in length and width compared to the other buildings. This most probably reflects the smaller scale of the buildings relative to the larger Church structures that included larger structural support for towers.

6.15.3 We instead surmise that the building was smaller in scale as evidenced by the smaller block dimensions and smaller areas of the site. The discrete and extensive remains may mean that it was also relatively intact at the time of collapse, perhaps due to change of occupancy on its closure in 1545. Certainly this is the case with St Francis chapel, which was converted into a house. The site has had a similar time period between closure to loss and time in littoral environment to other sites which suggests that these factors are not the reason for the difference in the scale of the ruins.

Ruin	Date of Closure	Date of Loss^	Time as ruin on land (years)	Time in Littoral zone (years)
St Katherine's Chapel	Dissolved 1545	*c.1550* c. 1650	c. 105	c. 362
St Peters Church	1654/55	*1695-1702* 1695-1702	c. 41-48	c. 310-317
St Peter's new (Town hall ?)	c. 1702-1716	*1702* 1620-1650	????	c. 392-362
Blackfriars	1538 – ruins shown in 1587	*1717* 1670-1710	c. 132-172	c. 302 - 342
Blackfriars new	1538 – ruins shown in 1587	*1717* 1700 - 1720	c. 179	c. 312-292
St Nicholas Church	1360-1380	*1450-80* 1660-1680	c. 280-320	c. 332-352

^ *italics* is as recorded in documentary record. Full text is prediction from coastal change analysis.

Table 5 Summary of each site in terms of its history of dereliction and time spent in the littoral environment.

6.15.4 Analysis of the block data shows that there is no statistically significant difference (t-test $P<0.05$) between the length and width of the largest blocks at St Peter's, Blackfriars and St Nicholas sites. However, there are significant differences between these three sites and the new site south of St Peter's and the St Katherine's chapel site. Both have much smaller block dimensions compared to the other Church sites. The new site south of St Peter's has more rounded blocks, with significantly smaller block length than St Katherine's chapel. However the latter may be an artefact of the Sidescan imaging. No data was available to make a similar comparison for the new Blackfriars site.

6.15.5 We undertook further statistical analysis using linear regression modelling to establish if there was a relationship between the size of the largest blocks and the time that a building was in ruins or had been in the littoral environment. There was no significant relationship, thus for this small sample, these factors were not controlling the formation of block size. Rather, the results of the site level analysis support the hypothesis that the size and area of the ruins on the seafloor are a function of the scale, type and state of the building at the time of collapse down the cliff. Larger sites tend to occupy larger areas and sites with towers, contain larger blocks of rubble and mortar masonry. Smaller buildings occupy a smaller area and are composed of smaller blocks, a function of the scale of the initial structure.

7 ANALYSIS OF HERITAGE RISK (OBJECTIVE 5)

To use the historical data (O1) to formulate estimates of coastal recession with which to estimate the risk to existing terrestrial heritage at the Dunwich site.

7.1.1 Analysis of coastal change was undertaken in order to better understand the timing of the loss of the town of Dunwich. The analysis is based on digitizing the shorelines at various dates, and using these to map the position of the shoreline over time. From this data it is possible to hindcast and forecast cliff positions assuming no change in conditions driving cliff retreat or geological composition of the cliff itself (Brookes & Spencer 2010). Dunwich is relatively unique in having surveyed data going back to the late 16th century, and contextual descriptive data back into the 13th and 14th century. A key objective was to use this data to build an empirical model of shoreline retreat as a basis for understanding the risk to existing landward heritage from coastal erosion, and to provide an estimate for the eastern position of the town.

7.1.2 Drawing upon the various sources available, the shorelines were digitized and incorporated into the Digital Shoreline Analysis System - DSAS (USGS, 2011; Brookes and Spencer 2010). This analyses change between mapped coastlines for different time intervals by establishing a shoreward baseline and then running a series of equally spaced transects across the digital coastlines. The software automatically creates intersections where the coastlines cross the transects and then works out the distances and a variety of coastal change statistics. Model development requires a series of digital coastlines each with a date and an estimate of the uncertainty which is the sum of digitizing, cartographic and georectification errors (Downward 1995).

7.1.3 Table 6 shows the periods of data that were chosen and their associated errors are also shown. While other years were available, these were rejected since the magnitude of change was less than the uncertainty for that map. Therefore, the chosen dates aimed to reflect the best spread across the available data. Where OS publication dates were available for the tiles, the latest publication date for the tiles was chosen, as the quoted dates for the different Landmark epochs, refer to the whole country not specific tiles, making it less reliable for this area. In addition the worse accuracy figures were used in order to provide a conservative figure for the analysis.

Source	Publication Date(s)	Quoted Dates	DSAS Date	Comments	GIS RMSE (m)	Accuracy (m)
Agas	1587	1589	1587	Redrawn by Joshua Kirby	10.1	13.32
Agas	1587	1589	1650	Redrawn by Joshua Kirby	10.1	13.32
Gardener	1754	1754	1700	Interpreted based on dates for loss of St Peter's church	10.1	13.32
Gardener	1754	1754	1729	Interpreted based on dates for loss of St Peter's churchyard	10.1	13.32
Gardener	1754	1754	1753	Current coastline shown as dotted line on the Agas map	10.1	13.32
Downing	1772	Unknown	1764	Estate map	23.2	28.1
Downing	1800	Unknown	1800	Estate Map	12.1	11.0
Tithe Map **Church of England Parish Map**	1826 1817		1826 1817	2 maps were used for this period. The more detailed Tithe map is used for most of the area with a small extension to the south based on the parish map. For the purposes of DSAS, the mean error was used. 9.45	5.0 13.9	5.8 12.8
Ordnance Survey First edition	1884	1849-1889	1884	1: 2,500	5	
Ordnance Survey First Revision	1904		1904	1: 2,500	5	
Ordnance Survey Second Revision	1927		1927	1: 2,500	5	
National Monuments Record / RAF Aerial Photography	1940		1940		4	
Ordnance Survey Third Revision	1938-1951		1951	1:1,0560	5	
Air Photography	1960's		196?		4	
Latest National Grid	1976-1989	1969-1995	1989	1:10,000	3.5	
EA Aerial photography	1992, 1997		1992		2.5	
OS Landline	2000		2000	1:1,250-1:2,500	1-2.5	
EA Aerial photography	2003 - 2009		2005		2.5	
EA 2010 Aerial photography	2010		2010		2.5	

Table 6 Datasets available for use within the DSAS coastal change analysis. Emboldened data represent those whose distance of cliff retreat was larger than the error.

7.1.4 The transect spacing was set to 20m. This represents a balance between capturing variability in cliff recession along the coastline, and the scale of the detail of the cliff survey. The transects and input layers are shown in Figure 36 below.

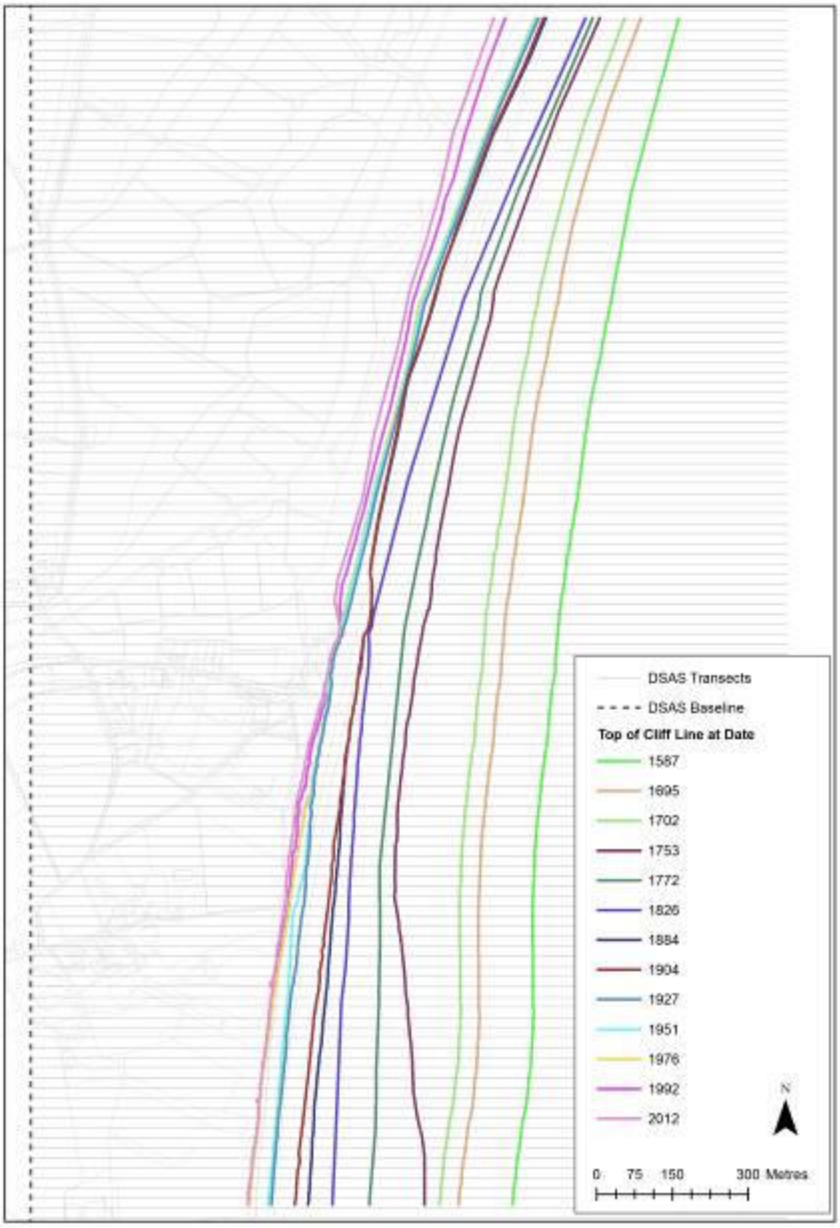


Figure 37 DSAS Analysis Transects and Top of Cliff Positions over time

7.1.5 For each transect the data was viewed and an appropriate statistical model constructed based on least squares regression. Whilst it was possible to apply models that provided a better fit to the data (e.g. second order polynomials), they did not reflect the process behaviour of the cliffs. For example, fitting 2nd order polynomial curves resulted in cliff growth when forecasting cliff position, despite a high goodness of fit to the existing data. It became clear that there was a change in the shoreline behaviour between 1904 and 1927, with a much reduced cliff retreat after this date. We therefore constructed two linear models for each transect based on data from 1587 to 1904 and from 1904 to 2012. The former were used to hindcast shorelines at 50 year intervals back to 1050 A.D., while the later were used to forecast coastlines in 2050 and 2100. Figure 37 shows examples of these models for sites to the north (gravel barrier) and south (cliff) of the town site.

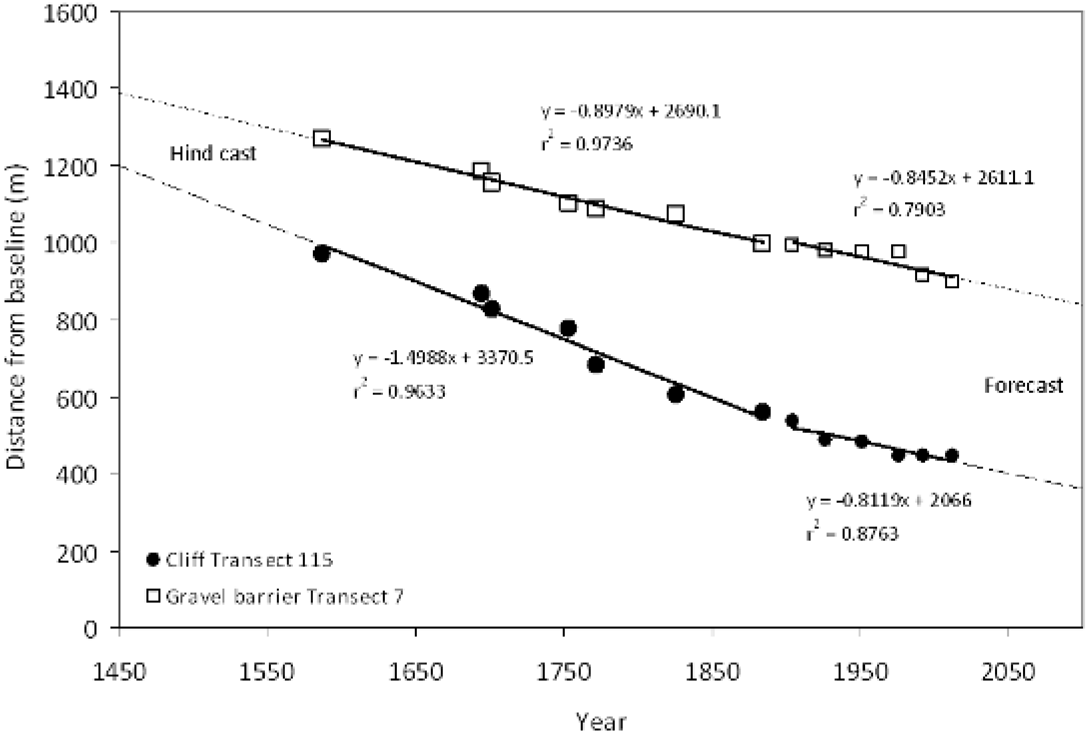


Figure 38 An example from two transects illustrating the shoreline forecast and hind cast modelling used to determine the former extend of Dunwich town to the east (seaward) and to asses risk to landward heritage. Uncertainty around these estimates are not shown for clarity, but reported in the accompanying text.

7.1.6 Projected coastlines are shown in Figure 38 below, which were derived by fitting linear curves to the historic coastal trend data at the transects shown in Figure 37. There are uncertainties associated with each shoreline position due to errors in the cartography, digitizing and within the linear models. The models themselves incorporate the errors within the processing of the data, so an estimate of the uncertainty can be derived based on the Root Mean Square Error (RMSE) for the observed vs modelled coastline positions at each transect. The average RMSE for the hind cast are ±31.4m for cliff and ±17.1m for the gravel barrier models. For the forecasts, the equivalent values are ±53.5m for cliff and ±7.4m for the gravel barrier models respectively.

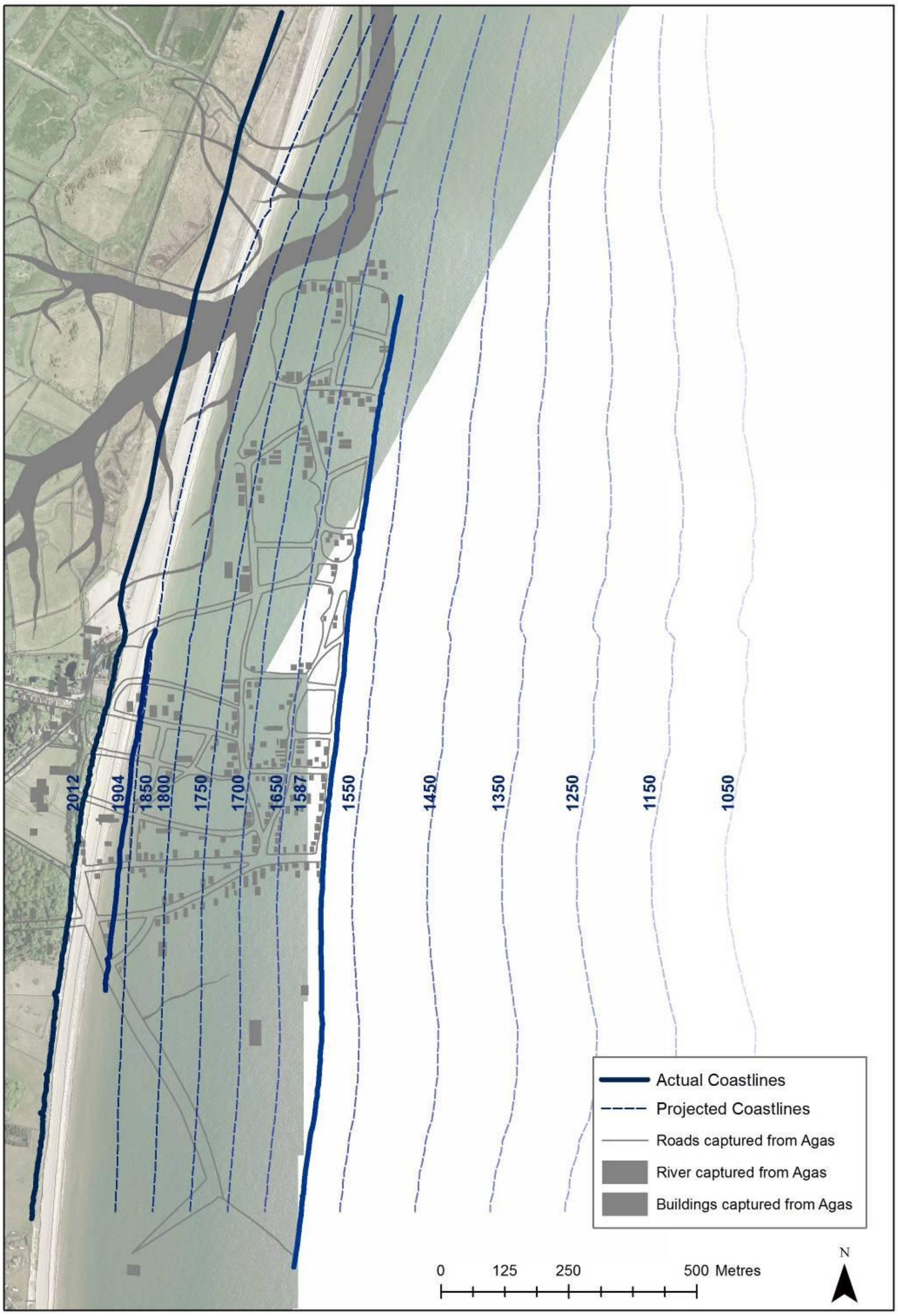


Figure 39 Projected and observed coastlines estimated from linear extrapolation of the position of the top of the cliff at each 20m transect line. Errors are not shown for clarity.

7.2 BATHYMETRIC CHANGE ANALYSIS (BCA)

7.2.1 Coastal change at Dunwich is though to be partly driven by changes in offshore bathymetry, notably the development of offshore sand banks

(Carr 1979; Blackley 1979; Pye and Blott 2006, 2009). Furthermore, development and migration of sand banks and interbank channels are important in terms of our understanding of the exposure and burial of the archaeology associated with the Dunwich town site. Thus an analysis of the seabed dynamics both synoptically and locally around the ruins is necessary for understanding the exposure and burial of the archaeology over the town site over longer timescales as well as during shorter timescales at which the ruins interact with tidally induced currents.

7.2.2 Bathymetric change analysis (BCA) is based on analysing the changes in bathymetry from depths extracted from historic hydrographic charts. We collated a series of bathymetric charts spanning the period 1782-present. Data was converted to a single map projection and chart datum was standardised, prior to differencing sequential charts. Analysis took three forms; (1) synoptic differencing to identify bank and channel evolution around the Dunwich site, (2) time series analysis of specific sites to identify the magnitude and trends of scours and sediment accumulation over key archaeological and to track the development of offshore banks, and (3) high-resolution analysis of key sites to support understanding of short term sediment-structure interactions.

7.3 Data Conversion

7.3.1 Many of charts were available in digital format but where necessary, charts were scanned into digital format and georeferenced in ArcGIS 10.2 in order to allow overlay and analysis. The georeferencing was based on the chart's coordinate grid, where available, but otherwise made use of a series of control points: identifiable features (e.g. roads / field boundaries) on the map for which the coordinates could be derived from other sources. Typically this involved *co-registering* the map to an existing map already in GIS format. The Root Mean Squared errors (RMSE) errors provide a measure of the accuracy of this process in each case and are reported in table 7 below.

7.3.2 Once the charts were geo-referenced, the bathymetric soundings were captured as a GIS vector (point) dataset and then interpolated into raster format (using a natural neighbour function in ArcGIS 10.2 3D analyst) in order to create a continuous depth surface of the seabed for each available period. The raster grids were aligned to a common raster framework in order to ensure there was no mismatch between cell boundaries.

7.4 Data Standardisation

7.4.1 Different datums and measurement units were used on the various charts and surveys. Therefore, in order to allow for direct comparison between the charts, the depths were standardised to *positive* metric units and to Ordnance Datum Newyln (ODN). The unit conversion factors and offsets are described in the table below and were derived through consultation with the UKHO Admiralty Tides team (Table 7).

Chart	***Year***	***Description on Chart***	**Horizontal Accuracy ***	**Unit Conversion to m**	**Datum Offset (m)**
A602-df	*1782*	*Fathoms unless it says feet - Depths of water as well as dry parts of the sands are at low water spring tides*	+/- 342.9m	conversion fathoms to metres (multiply by 1.83m	Add 1.28m offset for Southwold
102-A1	*1824*	*Soundings are in fathoms and reduced to low water spring tides (same as below)*	+/- 62.6m	Convert to metres multiply by 1.83	Add 0.53m
1630-A2	*1843*	*Note there is no information on the chart here so we assumed it was the same which is reasonable according to UKHO*	+/- 23.05m	conversion fathoms to metres (multiply by 1.83m	Add 1.28m offset for Southwold
102-B1	*1867*	*Soundings are in feet - datum for the soundings 11ft about the sill of the lock at Lowestoft harbour and 22ft below the top of the step at the gate of Orfordness high Lt. Ho.* <u>Same as below which references OD</u>	+ / - 21.2m	Convert to metres multiply by 0.30	Add 0.53m
102-C1	*1867*	*Soundings are in feet - datum for the soundings 22ft below the top of the step at the gate of Orfordness high Lt. Ho. Or 1 ft 9 inches below Ordnance Datum - or approx. MLWS using Southwold value*	+/- 41.0	Convert to metres multiply by 0.30	Add 0.53m
1630_B1	*1873*	*Fathoms - <u>Heights</u> are given in feet above ordinary high water springs*	+/- 31.1m	conversion fathoms to metres (multiply by 1.83m	Add 1.28m offset for Southwold
1630-C2	*1887*	*Fathoms - <u>Heights</u> are given in feet above ordinary high water springs*	+/- 46.8m	conversion fathoms to metres (multiply by 1.83m	Add 1.28m offset for Southwold
102-D1	*1933*	Note soundings are in fathoms but where less than 11 are in fathoms and feet *Reduced to 4.8ft below Ordnance Datum (Newlyn)*	+/- 45.6m	Convert to metres multiply by 0.30	Add 1.46m
	2008	*Survey by EMU Limited*	*** < 10m	Multiply by -1 so depths are positive	

	2012	*Survey by Wessex Archaeology*	*** < 10m	Multiply by -1 so depths are positive.	Offset by a sloping surface based on the differences between the depths of masonry blocks identified in both 2008 and 2012 datasets (2102-2008).

Table 7 Horizontal accuracy refers to measurement error for 2008-2012 and georeferencing errors for the earlier charts

7.4.2 Difference maps were created between the available years in order to quantify bathymetric change (erosion and accretion). This was achieved using the Map Algebra tools within ArcGIS 10.2 Spatial Analyst and involved simply subtracting the earlier map from the latter. This gave positive change values for erosion (ie the bed gets deeper) shown in red on the plots and negative change values (ie the bed gets shallower) shown in blue on the plots. The difference map extents cover the intersection of the input datasets.

7.4.3 In addition to the synoptic change, difference maps are also shown for the higher resolution bathymetry datasets. Difference data for the six main structures were given earlier. Finally, we calculated the change in maximum elevation of the Dunwich sand bank and the minimum elevation for the trough within which most of the exposed archaeology resides. The latter were generated to test the hypothesis that the reduction in cliff erosion since the 1920's had been influenced by the accretion of the Dunwich Bank (Pye & Blott 2006).

7.5 Synoptic Bathymetric Change

7.5.1 The evolution of the coastline at Dunwich is controlled by the interaction of alongshore sediment supply and transport, migration and elevation of Dunwich bank, tidal flows, wave regime and storm surges. Cliff erosion at Dunwich is fundamentally controlled by the erosion cycle that starts with erosion of the toe of the cliff, followed by collapse of the upper cliff. Sediment from this is either transported away or accumulates at the toe. If the latter occurs, then the cycle can only progress once this material has been removed. Material at the toe of the cliff can come from the development of a beach, or from collapsed cliff material. Erosion is driven by the excess energy above a critical threshold height set by the elevation of the toe of the cliff. If water (either during tide, wave or storm surge) does not reach the toe of the cliff, then no cliff erosion can occur except by the processes of mass failure or sub aerial weathering of the cliff face.

7.5.2 Cliff erosion will increase in the absence of or a low beach elevation, or during periods when the height of the sea is greater than the tow elevation, which is during high tides, storm surges and or storm waves. The development of offshore banks act to reduce wave height shoreward, hence reducing the elevation of the sea at the coast.

However the effectiveness of this process depends on the depth of water over the bank. Hence, evolution of offshore banks and changes in the elevation of the bank crest over time will act to moderate the effects of storms to a greater or lesser extent. Similarly, absence of a beach or lowering of beach elevation over time will control cliff toe erosion (Lee 2008). Robinson (1980) and Haskoning (2001) demonstrate that for larger waves (>2.2m) there is a 0.5m reduction in wave height at the coastline as a result of the Dunwich bank.

7.5.3 At the gravel barrier and lower lying land to the north of Dunwich, processes of erosion occur in response to sea height as with the cliffs, but the result is different. During periods of high water elevation relative to the barrier elevation, the beach can steepen is material is removed, and the barrier narrows until overtopping and breaching occur. During these processes, the barrier sediments are transported onshore into the back barrier marshes, and the overall elevation of the barrier decreases, and the barrier widens (Pye & Blott 2009). The net effect over time of these processes is the progressive breakdown and migration of the gravel barrier landward over the marshes. This process is arrested by supply of sediment down-drift (from the north) and periods of beach building.

7.5.4 On low lying land, the erosion process is similar to that for higher cliffs at the seaward margin, but experiences additional processes during shallow overland flows once the sea exceeds the land levels. Erosion of the seaward margin is controlled by the presence of a protective beach. Both shallow cliff erosion and overland scour are driven by the height of the sea relative to the elevation of the toe of the cliff and the land surface. The Fisk photo's of the aftermath of the 1911 storm shows how this process creates a steep low height cliff, and has the ability to scour away the beach. Gardner (1754) describes the overland scouring process of the 1740 storm, that flattened the 40ft (12m) Cock and Hen hills and scoured away the low lying land down to reveal the graves and foundations of buildings.

7.5.5 Studies of the evolution of the Sizewell-Dunwich Bank have identified that during periods of higher wave energy, cliff erosion to the north supplies relatively large volumes of sediment to the coastal zone to the south (EDF 2012). Alongshore transport delivers sediment onto the Sizewell beaches and then possibly to the Sizewell-Dunwich Bank from Thorpeness, raising its height and offering more protection from waves to the adjacent coastline. Cliff erosion (at least from Dunwich cliffs) and sediment supply to the Sizewell-Dunwich Bank will then reduce in response to the higher bank and lowered inshore wave climate. In turn, bank volume and height will decline with time, and inshore wave energy levels and cliff erosion will rise again (EDF 2012). Thus, in order to understand the riss to the site from coastal erosion and bathymetric changes, requires some consideration of offshore morphodynamics.

7.5.6 The Walberswick – Minsmere section of the seabed, was completely surveyed by the Hydrographic Department in 1824, 1867, 1873, 1887, 1930, 1940, 1965 and 1987 (Lees, 1977). During this period, it is well known that the Sizewell and Dunwich banks extended north and amalgamated (Pye & Blott 2006, Lees, 1977). Moreover, both banks, and in particular the Dunwich bank opposite Minsmere sluice, migrated east (landwards) over the period. However, what is less well known is the change in alignment and crest elevation up to date. Figure 41 shows the general bathymetry and highlights the migration of crest and trough lines over time, whiles Figures 42 and 43 show bathymetric change over time.

7.5.7 Between 1782 - 1824 Sizewell and Dunwich banks were separate and aligned NNE to the coast at Dunwich. Between 1824 and 1867, Sizewell bank extended north, raising bed levels by up to 10m, though at time of survey the two banks were still separated. A trough developed landward of the banks during this time, though again this was not continuous (Figure 39). Erosion close inshore created a trough that extended south past the town site. Accumulation of sediment occurred more generally across the area during this period. The Sizewell bank at this time had an amplitude of *ca.* 8 m above the surrounding seabed while the Dunwich Bank was smaller with an amplitude of only 3 m above the surrounding seabed, with the highest point some 7 m below Chart Datum (Lees 1977).

7.5.8 Between 1867-1873, Figure 39 shows that although the sandbanks remained disconnected, both banks migrated landward. The whole area generally experienced erosion. Between 1873 and 1887 the bank systems migrated further landward during a period of less coherent patterns of sediment accumulation and erosion. Erosion occurred over the Dunwich town site during this period and along the shoreline. The Sizewell bank system during this period was aligned to the north, whereas the Dunwich bank was still aligned NNE.

7.5.9 A Significant change occurred between 1887 and 1922 with the coalescence of the Dunwich-Sizewell bank system, and the re-alignment of the Dunwich bank to the north. Sediment accumulation occurred over the Sizewell-Dunwich bank, and both migrated landward. Lees (1977) reports that by 1940 the crest of the bank generally lay 4–5 m below Chart Datum, with an amplitude of 5–6 m above the surrounding seabed. This corresponds with the general accumulation (shallowing) of the area off Walberswick-Minsmere shown in Figure 40.

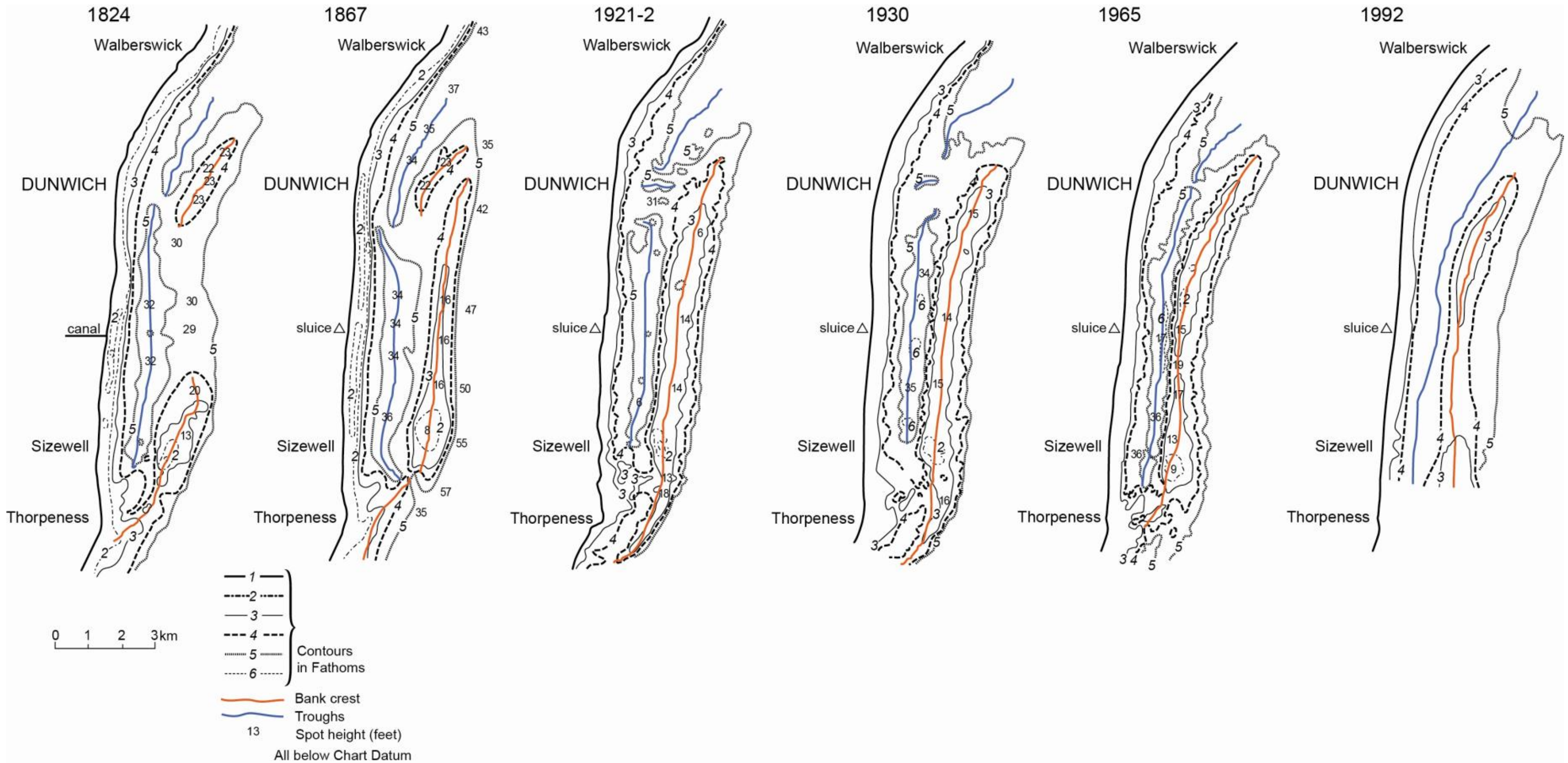


Figure 40 Synoptic bathymetric change analysis in Dunwich bay. The crest lines of offshore bank are shown in red, whilst trough lines are shown in blue. Two transects are shown as red pecked lines to highlight the migration of offshore banks and troughs over time. The main features is the northern extension of Sizewell bank and its coalescence with the Dunwich bank. West (landward) migration of the Sizewell-Dunwich bank system can be seen.

7.5.10 Between 1930 and 1965, the alignment of the northern Dunwich bank changes and moves towards the NNE (Figure 41). Although a continuous ridge extending from Dunwich to Thorpeness was still present, a low point in the ridge had formed just to the south of the sluice at Minsmere, and Dunwich and Sizewell Banks could once again be recognised as separate features (Lees 1977). This general morphology has continued until the present (2010). Importantly, the Sizewell-Dunwich ridge eroded and widened between 1930-1965 with the crest lowering by 1m to ca. 4 m below Chart Datum (Lees 1977). Conversely, the area to the east of the banks accreted during this time.

7.5.11 Between 1960 and 1974, erosion continued, with a deepening of the low point between the two banks, south of Minsmere sluice. The crests of the banks were maintained at c.3–4 m below Chart Datum, and the position of the banks remained stable. To the east of the banks, the area continued to accrete. Erosion of the banks continued through the 1980s, as the chart of 1992 shows both Dunwich and Sizewell Banks shrinking further in size, although largely maintaining their crest height (Lees 1977; Pye and Blott 2006).

7.5.12 Pye and Blott (2006) report that Environment Agency surveys between 1992 and 2003, show that the crest of Dunwich Bank opposite the town site dropped *ca.* 1 m in elevation, and migrated landward by 100–200 m. The area to the west of the bank, continued to accrete as a result of infilling by sediment.

7.5.13 Figure 43 shows the net difference in bathymetry over the Dunwich town site between 1933 and 2008 MBES survey and the most recent change between 2008 and 2012 MBES. The scale of change is lower over the time period despite a longer gap between surveys (1930-2008) which may either mean we are missing the intervening changes, or that sediment processes are limited by available supply. The latter is favoured by Lees (1977). The area of analysis is also more limited due to the scale of the MBES datasets.

7.5.14 Accumulation has occurred since 1930 over the eastern (older) half of the Dunwich site, in response to the flattening and widening of the Dunwich bank over this period (Lees 1977; Pye & Blott 2009). In contrast, the area of the site shown on the Agas map of 1587, has eroded down, with a localised maximum at the southern end of the town site.

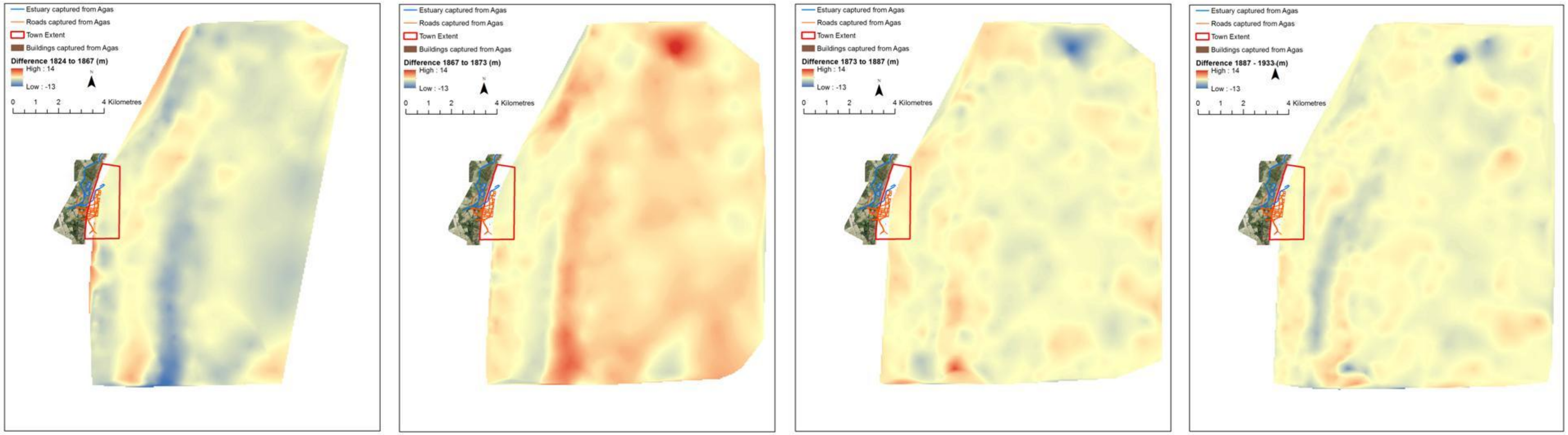


Figure 41 Synoptic bathymetric change influencing the Dunwich town site 1824-1933 derived updates to Admiralty bathymetric charts. Development and breakdown of sandbanks and troughs are evident as are phases of more general accumulation (1863) and erosion (1873) over the region. 1873-1887 reveals a period of less coherent bathymetric change. The Eastern margin of the site has tended to erode over this time period.

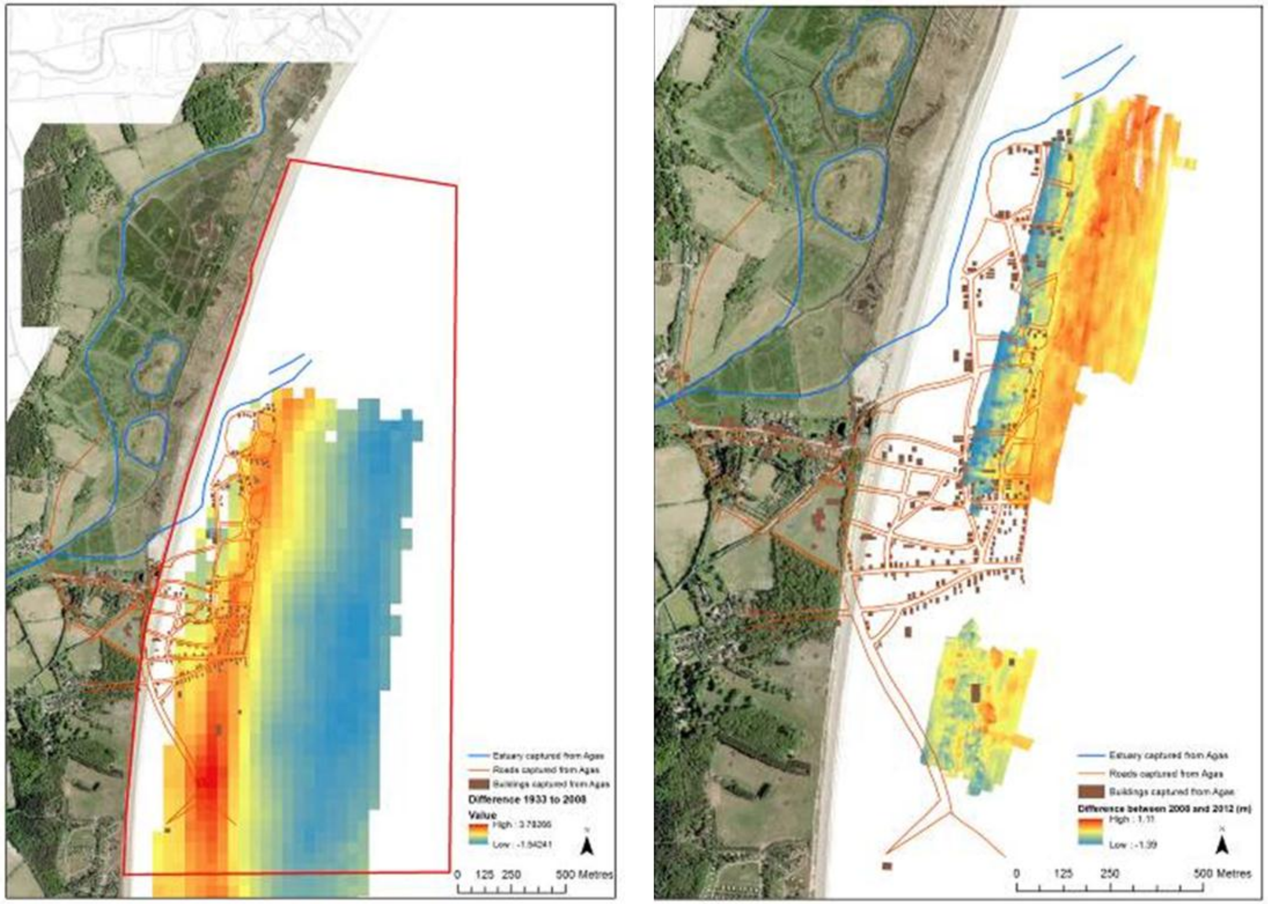


Figure 42 Bathymetric changes over the Dunwich town site based on 1930 Admiralty hydrographic charts and Multibeam surveys. Left hand figure shows accumulation (blue) over the eastern (older) half of the site and erosion (orange/red) over the area shown on the Agas map in the period 1930-2008. Values are much smaller than in previous years hence the change in scale. The right hand figure shows relatively limited change in bathymetry between 2012 and 2008, with accumulation over the middle section of the site where most ruins have been found, and erosion over the eastern area.

7.5.15 There is some evidence that the inner bank has accumulated over this period.

7.5.16 In contrast, between 2008 and 2012 MBES surveys (Figure 43), the eastern margin of the Agas map and area of the earlier town, saw a net loss of sediment, and a decrease in depth relative to chart datum. The central area of the town (where most of the main archaeology was exposed in 2008), has accumulated sediment. This is as a result of a more general offshore movement of the inner sand bank that borders the beach (Figure 42).

7.5.17 Buringham & French (2009) use maximum trough depth and bank crest elevation as measures of temporal change in coastal morphology. Repeating this analysis and including Environment Agency cross-sections (S1C5) reveal that Dunwich bank has reduced in elevation since 1930 and continues to flatten and widen (Figure 46). This has important implications for inshore wave climate and storm wave height (EDF 2012, Stansby et al., 2006). At the same time maximum depths in the trough seaward of the bank, which includes part of the Dunwich town site, have decreased as sediment accumulates with the widening of the Dunwich bank (Figure 43).

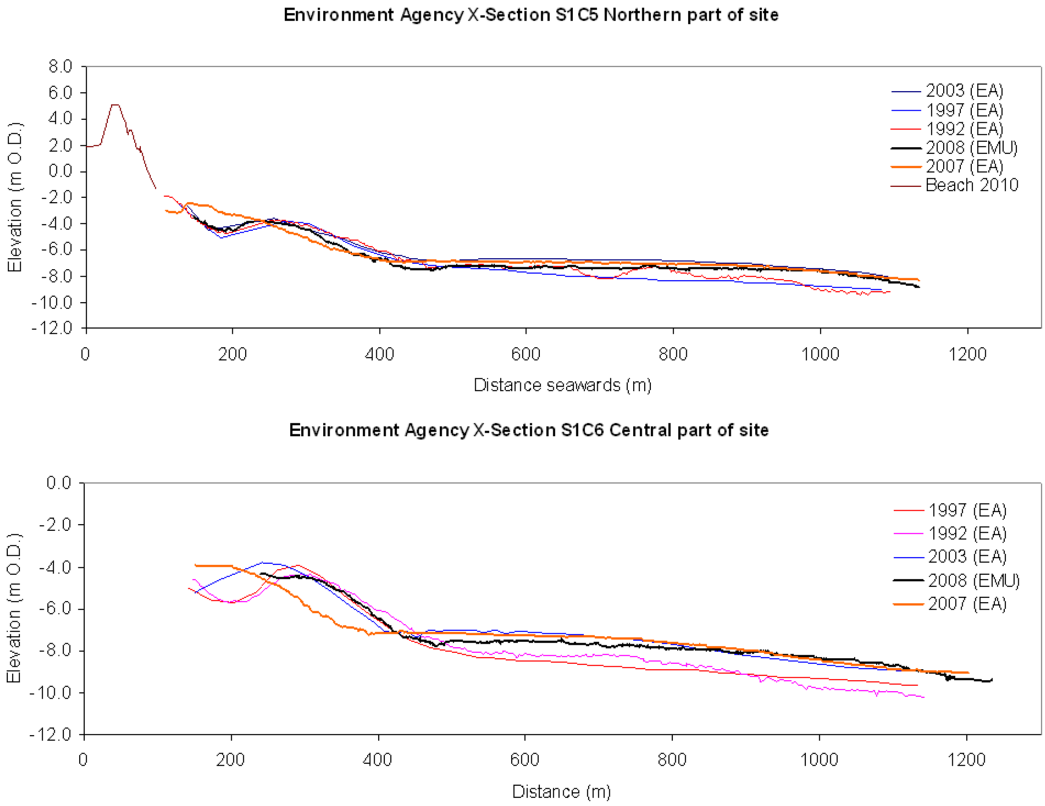


Figure 43 Bathymetric changes across the northern and middle sections of the Dunwich town site. The largest changes occur where morphological change occurs such as the migration of the inner sand bank between 200-400m from datum.

7.6 Site Scale historic changes in seabed Bathymetry

7.6.1 Using the bathymetric data it is possible to determine change in the elevation of the seabed for a 25m buffer around each of the main archaeological sites. These include the new sites at Blackfriars (18) and south of St Peter's church (3, 4, 53) collectively called 'Blackfriars New' and 'St Peter's New' (Figure 45).

7.6.2 Figure 45 demonstrates how variable the average seabed elevation is around the sites, and how narrow the range of elevations are at a site over the 25m buffer (shown by the range bars in Figure 45). The width of the grey shaded area varies with the survey density (fewer bathymetric points pre 1933). Errors in the data arise from differences in the methods of depth estimation (lead lines to sonar), unit conversions (fathoms, feet, metres) and in the accuracy (nearest 0.3m in depths <20m for early charts). Van der Wal & Pye (2003) suggest that changes within ±0.58m could not be classed as significant; a value adopted by Burningham & French (2008) in their analysis of historic seabed change in the Thames Estuary.

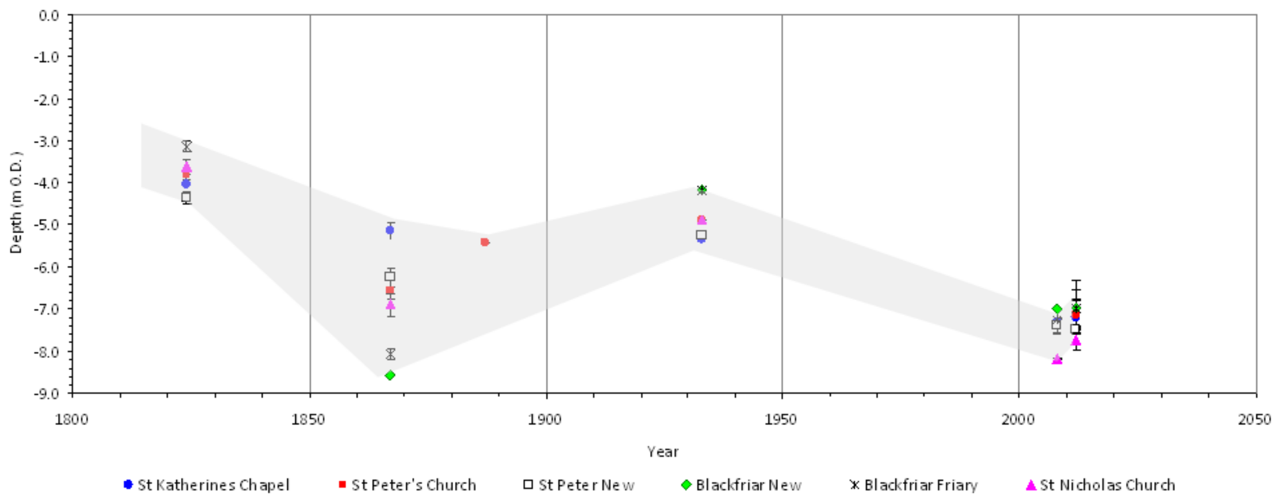


Figure 44 Historical bathymetric change at each of the main marine archaeological sites. Grey area defines the trend and range of changes across all sites. Current bathymetry is advantageous for the exploration of the ruins at all sites compared to those in 1933 and 1824, when 2 – 3m of sediment must have covered the sites.

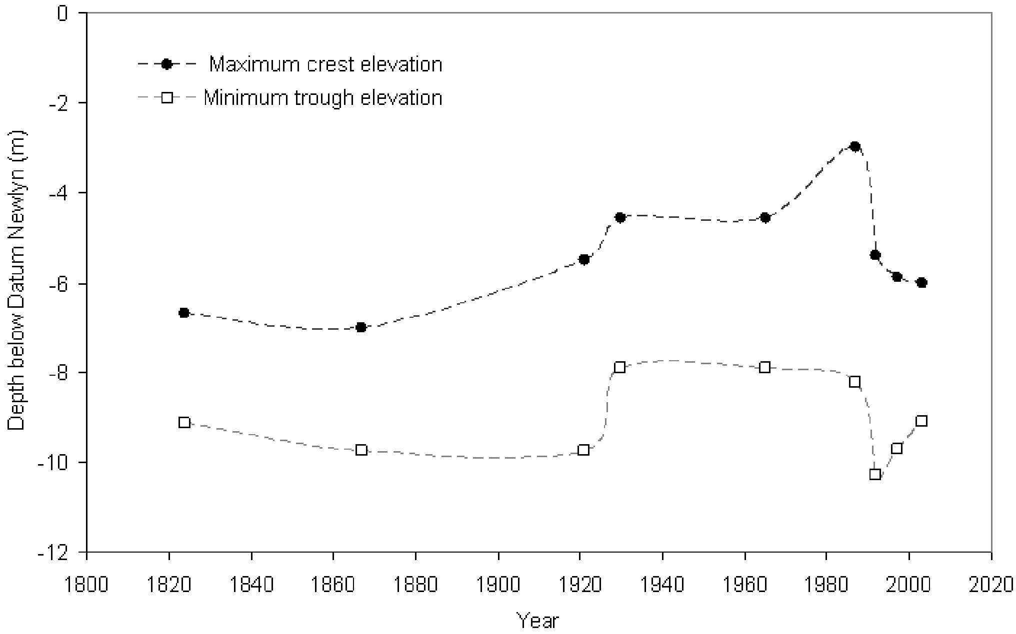


Figure 45 Temporal changes in the maximum crest elevation and trough depth opposite the Dunwich town site. Crest elevation is inversely related to inshore wave climate, and has been linked to reductions in cliff erosion at Dunwich since c.1920 Trough elevation is a measure of the storage of sediment over the eastern half of the Dunwich town site.

7.6.3 All the changes in Figure 45 are greater than 0.58m between periods of survey. Variability in average seabed elevation over each site over the whole period, ranges between 3.1 – 4.9m. These values are consistent with the scale of changes measured by Burningham and French (2008) for an area of the Suffolk coast just south of Dunwich over this period. For example, maximum bathymetric changes at Aldebrough Napes, 8km south of the site, were 4.9m over the same period (Burningham & French 2008).

7.6.4 Bathymetric surveys undertaken by the Environment Agency show changes in sea bed elevation of up to 2m in regions of morphological change (ie where the inner sand bank moves offshore) and up to 1.4m in regions with a more simple morphology over time periods of 1 – 18 years (Figure 44). The EA surveys show no landward migration of the inner sand bank over the past 18 years, consistent with the limited cliff migration over this period.

7.6.5 The height of the larger masonry blocks making up the marine archaeology at the sites is typically <1.0m. Thus, the scale of change recorded over the sites and at sections across the town, over the historic and more recent surveys is capable of completely burying or uncovering the archaeology. Figure 45 shows that the surveys undertaken in 2008-2012 have been during a period when the ruins were most likely to be exposed. A similar period occurred in 1867, but at other times, the sites must have been covered by several metres of fine sediments. Bacon (1979; 1988) report similar periods during the 1970’s and 1980’s when the ruins were visible and then buried. All

Saints church ruins have been buried since dives in the early 1970's by seaward progression of the inner bank and increases in beach level (the latter artificially increased in the 1980's (Bacon & Bacon 1988).

7.7 SEDIMENT MOBILITY AND SEABED TOPOGRAPHY AROUND INDIVIDUAL RUINS.

7.7.1 Bacon & Bacon (1979; 1988) report variability in the seabed topography during dives made over the town site during the period 1971- 1983. A feature of these dives was the continual change in the exposure and burial of the ruins that led to uncertainty over the nature and extent of the structures that were found.

7.7.2 The geophysical data collected in 2012 and 2009 show the nature of the interaction between the mobile fine sediment, tidal currents and the marine archaeology at the site. Where fine sediment lies over the seabed, the larger blocks are surrounded by a scour pit (Larrouse et al 1993, Quinn 2006) Figure 47.

7.7.3 Larger blocks and block fields interact with the tidal currents to generate local flow structures (vortices) that influence sediment transport. This results in the formation of horseshoe vortex scour pits around blocks and in some cases scour channels either side of the blocks that extend for several block widths downstream of the obstacles (Figure 48). Regions of recirculation and low velocity in the lee of the blocks accumulates fine sediment and results in a "rats tail" in the direction of major flow. At the Dunwich site, this is most evident at the south of the site around the ruins of St Nicholas church. Tidal flow is broadly north-south, but the dominant flow is to the south. This corresponds with the direction of drift, and with tidal current measurements made in the area (Lees 1977).

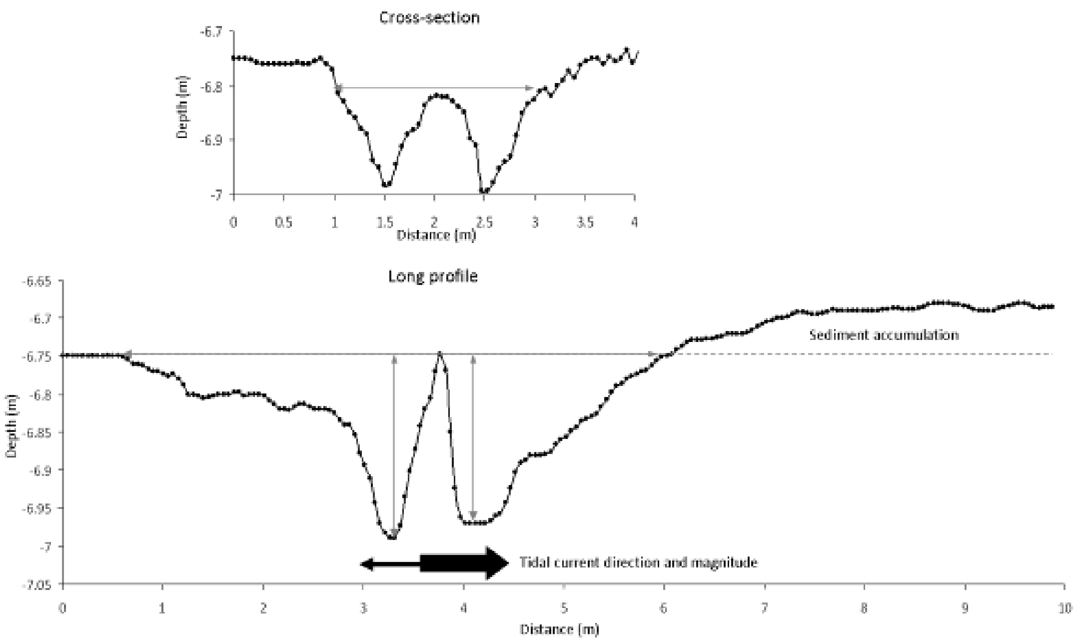


Figure 46 Scour around a single block showing in long=profile direction of tidal current and cross-section. Note the increased depth of scour on the upstream face resulting from vortex generation at the face of the block, and the accumulation of fine sediment down-current in the region of lower pressure/velocity down-current of the block. Cross-section shows how the horseshoe vortices creates scour around the block as in Figure b.

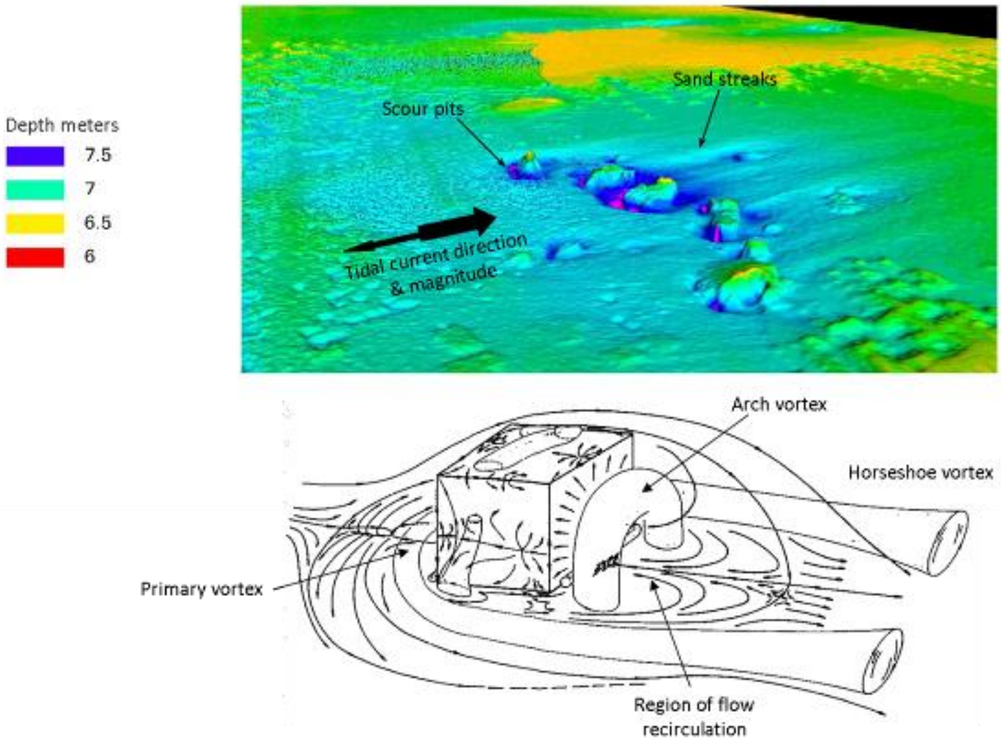


Figure 47 Evidence for the interaction of fine sediments, tidal currents and marine archaeology. **A)** scour around blocks of masonry and formation of scour channel and "rats tails" of sediment in direction of main tidal current. **B)** Conceptual model of flow structures developed around a block after Larousse et al (1993).

7.7.4 Larger areas of blocks appear to generate their own area of scour, again with an asymmetry in the southerly direction (Figure 49). At the Blackfriars site, large sand waves are partly burying ruins. Their movement over the site will continue to bury and reveal the ruins in this area.

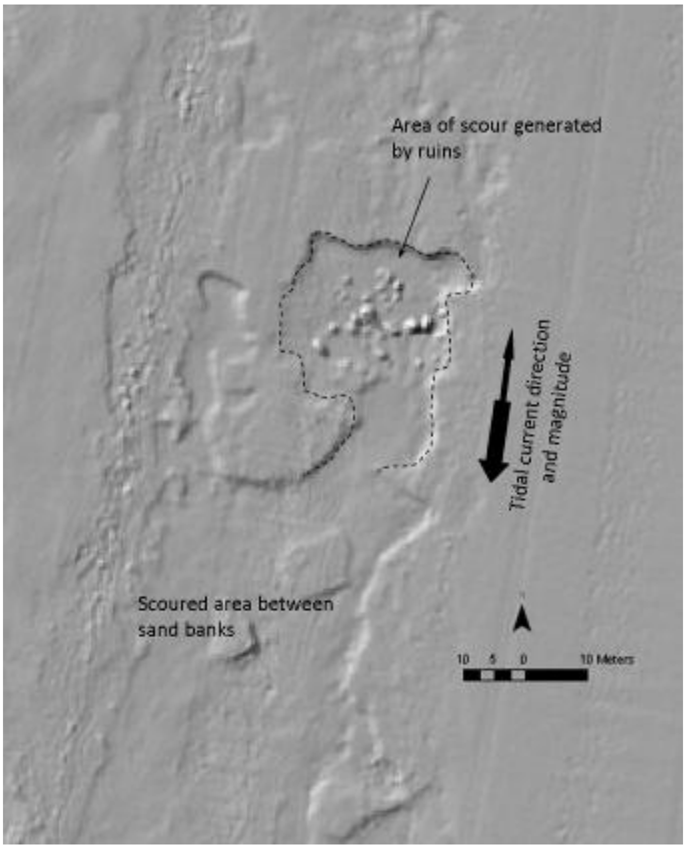


Figure 48 larger scale interaction between fine sediments and multiple masonry blocks showing an area of scour into the underlying bedrock. Areas o mobile fine sediments surround the scoured area.

7.7.5 Bathymetric change analysis at the scale of the individual sites over a period of 4 years between 2008 – 2012 surveys reveals variations at two scales. First, the movement of sand waves and the margins of the inner and outer sand banks creates large areas of bathymetric change, including the infilling of the scoured area around the ruins of St Nicholas church. Second, there is evidence for the development of localised scour and accumulation around individual blocks and groups of blocks, driven by the flow – obstacle interactions described above. We can conclude that the site, lying within the shallow littoral zone is dynamic, with changes in seabed elevation occurring across a range of spatial and temporal scales. These result in variable seabed conditions over the Dunwich town site that causes exposure and burial of the archaeology. The current trajectory appears to be one of a reduction in the elevation offshore sandbanks as they widen, and an increase in sediment accumulation of sediment in the trough where most of the archaeology is currently visible.

7.8 SUMMARY AND RISK TO THE MARINE HERITAGE

7.8.1 Figure 50 and Table 8 summarize the loss of archaeology and land due to coastal erosion between 2012 (current) and 2100. Loss of the last of the main medieval town enclosed by the Pales Dyke is forecast by 2100+error, and all but the northern area of the town is forecast by 2100 less error. Although a considerable uncertainty surrounds these forecasts, there is a strong probability that the last of All Saints Churchyard and associated roads within the boundary of the Pales Dyke will be lost over the next 40 years.

2050 AD	2100 AD	2100+Buffer
Last two gravestones in All Saints graveyard	Last two gravestones in All Saints graveyard	Last two gravestones in All Saints graveyard
All Saints graveyard	All Saints graveyard	All Saints graveyard
Duck Street	Duck Street	Duck Street
Scotts Lane	Scotts Lane	Scotts Lane
Kings Street	Kings Street	Kings Street
SE perimeter wall of Greyfriars Friary (GFF)	East perimeter wall of Greyfriars Friary (GGF)	Maison Dieu Lane
	Road between All Saints and GFF	East plus 60% of north and south perimeter walls of Greyfriars Friary (GGF)
	Building on south side of Middlegate street shown on Agas 1587 map.	Road between All Saints and GFF
		Pales Dyke defence ditch and bank
		Chancel of GFF
		Eastern half of friary buildings (GFF)
		Maison Dieu site
		Bridge gate
		7 buildings shown on Agas 1587 map

Table 8 Archaeology at risk from coastal erosion at Dunwich based on linear modelling of cliff positions over time since the change in cliff retreat post 1922. Sites are listed if they fall within the error envelope for each date.

7.8.2 This analysis supports the view that further excavation of the Pales Dyke and the area within its boundary should be undertaken within the next 10-30 years in order to determine the chronological sequence of site development. Specifically, this should focus on confirming recent Time Team evidence for a pre-medieval (Saxon) origin to the Pales Dyke, and to determine the sequence of urban development whilst the evidence is available. Once eroded (which can happen in a single storm) this evidence and context will be lost. Excavations should focus on Pales Dyke and road sections exposed in the cliff face, and on archaeology contained in the area around Scott's lane and Duck street north of All Saints churchyard.

7.8.3 The last of the original Dunwich gateways 'Bridge Gate' is also predicted to be lost within the next 80 years. This is an opportunity to learn as much as possible from the site, including evidence for the age of he gate and its sequence of development. As such a plan for the excavation of this site should be developed so that it can be implemented should cliff retreat threaten this heritage resource.

7.8.4 Additional, rapid consideration should be made on what to do about the gravestones and human remains interred within All Saints churchyard. Even at current low rates of erosion, loss of these is forecast in the next 25 years.

Figure 49 Future coastlines forecast using linear extrapolation of cliff positions 1904-2012. Buffer is based on RMSE for forecasts *vs* observed coastal positions. Archaeology at risk is summarised in Table 9.

7.8.5 The Hospital of the Holy Trinity (Maison Dieu) site (OCN SF142) is currently protected by informal coastal defences comprised of WWII concrete blocks and a bulldozed gravel bank. As a result the rate of coastal retreat through erosion is lower (Figure 50). However, forecasts show that the barrier and adjacent cliffs to the south are likely to retreat over the site within the next 40-80 years. Evidence from the 1911 photography demonstrates that this can happen rapidly when the beach is removed during a storm.

7.8.6 Greyfriars Friary (HER DUN092 and 094) is an extensive, relatively undisturbed site of a large Franciscan friary including the church, and outbuildings. The southern part of these buildings was developed as a house in the 18th century, and for a time other buildings were used or the town gaol and town hall. Recent surveys of the perimeter wall and geophysical and test trenches have revealed the plan and nature of the archaeological remains at the site. It is the largest remaining building complex from the medieval town.

7.8.7 Forecasts of future cliff line position indicate probable loss of the eastern perimeter wall over the next 40 years, with possible loss of the eastern friary buildings, chancel of the friary church, and current standing building ruins including remains of the 18th century Greyfriars house within the next 80 years.

7.8.8 The bathymetric change analysis has revealed three scales of sediment dynamics that interact to determine the extent to which the marine heritage is exposed and detectable using standard geospatial surveys. These are:

1) Regional synoptic development of of-shore banks and interbank channels driven by regional sediment budgets and the evolution of off-shore bathymetry and the coastline. This drives the long term burial of the eastern (older) area of the town as the Dunwich bank has migrated north and west, and as the inner sand bank develops and migrates west as the coastline retreats.

2) Migration of the margins of sand banks and sand waves over the site, partly driven by (1) but more locally expressed at the scale of the ruins. This results in the exposure and burial of individual sites over annual timescales. This is exemplified by the exposure of new sites in 2012, and burial of the St Nicholas site relative to 2008.

3) Interactions between the individual ruins and blocks, and the mobile sediments passing over the site.

7.8.9 Risks associated with sediment dynamics are a) erosion by attrition of the heritage caused by impacts from mobile sandy sediments during periods of exposure; and, b) obscuring of the marine heritage by fine sediment accumulation over the site. This currently frustrates the exploration of the older pre-Agas (1587) town. Conversely, burial of structures protects them from scour by mobile sediments and possible disturbance by divers / fishing gear.

7.8.10 The mobility of the sand banks over the site when compared with observations made by Bacon during dives in the 1970-sand 80’s indicates landward (west) migration and growth of the inner sand bank over the All Saints church site. Although not investigated by this project, the presence of the bank over the site is indicated by the beach bathymetry collected by the Environment Agency. Exploratory dives over this site (parts of which may be exposed in the narrow gully that runs along the tow of the beach) are advised to confirm this statement.

7.8.11 The ruins of the Temple and St Francis Chapel site, will eventually (be revealed by migration of the coastline and inner sand bank. Conversely, growth and coastal movement of the Dunwich bank will bury the existing exposed ruins. We can deduce that since these have been visible on the seabed since the 1970's, this process is likely to be slow, and their continued exposure will present both opportunities for learning and threats to preservation as identified above. Research to investigate the effects of sediment dynamics on masonry structures is required to determine the nature and magnitude of the risks. However, it is worth remembering that some sites (St Peter's Church, St Nicholas Church) have been exposed to sediment dynamics since at least the late 17th Century and earlier.

7.9 SITE EXTENT AND RECONSTRUCTION (OBJECTIVE 2)

To better define the northern and eastward extent of the former town and the location and form of any existing archaeological structures visible above the seafloor.

7.9.1 An important component of heritage protection is to define, in as far as is possible, the area of the site. With most wreck sites, this is a relatively discrete area defined by artefacts from the vessel, and the nature of post deposition wreck site evolution (Quinn 2006). In the case of Dunwich, the site area is partly on land and mostly in the sea. The area of the site is therefore determined by the scale of the original town, and the subsequent development of the site over the past c.800 years of coastal processes and land use.

7.9.2 We utilised a range of data sources to determine the area of the town. These included (i) primary data capture from archaeological excavations on land, and (ii) geophysical/diver surveys of the sea bed. We also used a range of secondary data sources including cartographical sources (maps, surveys, charts, as well as pictures contained in coastal pilots, literature and photographic and painting archives. We also used literature sources containing references to topographic and geographic data. Finally, we applied the coastal change analysis to derive the most probable eastern limits to the town. Figure 51 shows the most probable reconstruction of the Town.

7.9.3 To determine the eastern (seaward) limit of the town and to define the area of heritage protection, we selected a band incorporating the predicted positions of the coastline between 1050 – 1250AD. This incorporates the period of rapid town development from the Domesday survey (1089AD) through the peak in the town's economy (1176-1230), through to the first major blocking of the harbour 1250AD (Sear et al., 2011). The first major loss of buildings of note (churches and up to 400 houses) were in the storms of winter 1286-87. Prior to this, there is mention of the sea becoming close to the town (e.g. prompting the movement of the first Greyfriars friary from its north eastern site to the present in c.1258 AD), but not the destruction of significant urban infrastructure and buildings. Indeed, early records (1066-1089AD) refer to loss of a woodland and land, and problems related to disruptions to the harbour (Comfort 1994; Gardner 1754).

7.9.4 The most likely position of the eastern margin of the town is that shown by the coastlines in c. 1250-1300 AD. The Eastern margin of the town between 1250 and 1300 lies between 635 – 1049m east of the coastline in 2012, narrowing towards the north as the estuary develops, and the Dunwich/Blyth river exits into the sea. Using the town defences as the western margin, this results in an east-west width to the town of between 282 – 834m . Extending the towns defensive ditch round to the coast on the south, and tracking the Dunwich river to the north, gives a north-south length to the town of 1834-1922m (1.1 – 1.2 miles). The values correspond with early descriptions of the town as being approximately 1.0 mile (1.6km) in length (Gardner 1754). The width of the town was conjectured to be similar to the length, but this was based on the assumption that Dunwich was “like other towns” (Letter to Master Deye 1573, reproduced in Bacon & Bacon 1979). In fact there is no evidence to support this assertion.

7.9.5 Our analysis suggests that the town was elongated south of the river and was narrower in the north where the highland sloped into the Dunwich/Blyth river estuary. The wider area of the town lay on the higher land in which were built most of the main (and wealthy) religious houses, the market place and the town hall. This part of the town was enclosed pre 1175AD and probably during the Saxon period (Time Team 2012) by a ditch and embankment (Pales Dyke) to the west and south. To the north the Pales dyke may have curved around the high land including Maison Dieu hill. The Agas map of 1587 shows what looks like a steep western side to one of the unnamed roads northwest of St Peter’s church. While the steep reduction in elevation from Cock Hill to the level of the harbour is shown clearly in the Coastal Pilot charts of 1631 and 1671. This would be similar to the current situation and those shown in 19th Century paintings and photographs where Maison Dieu Hill dips steeply to Maison Dieu land and the level of the beach.

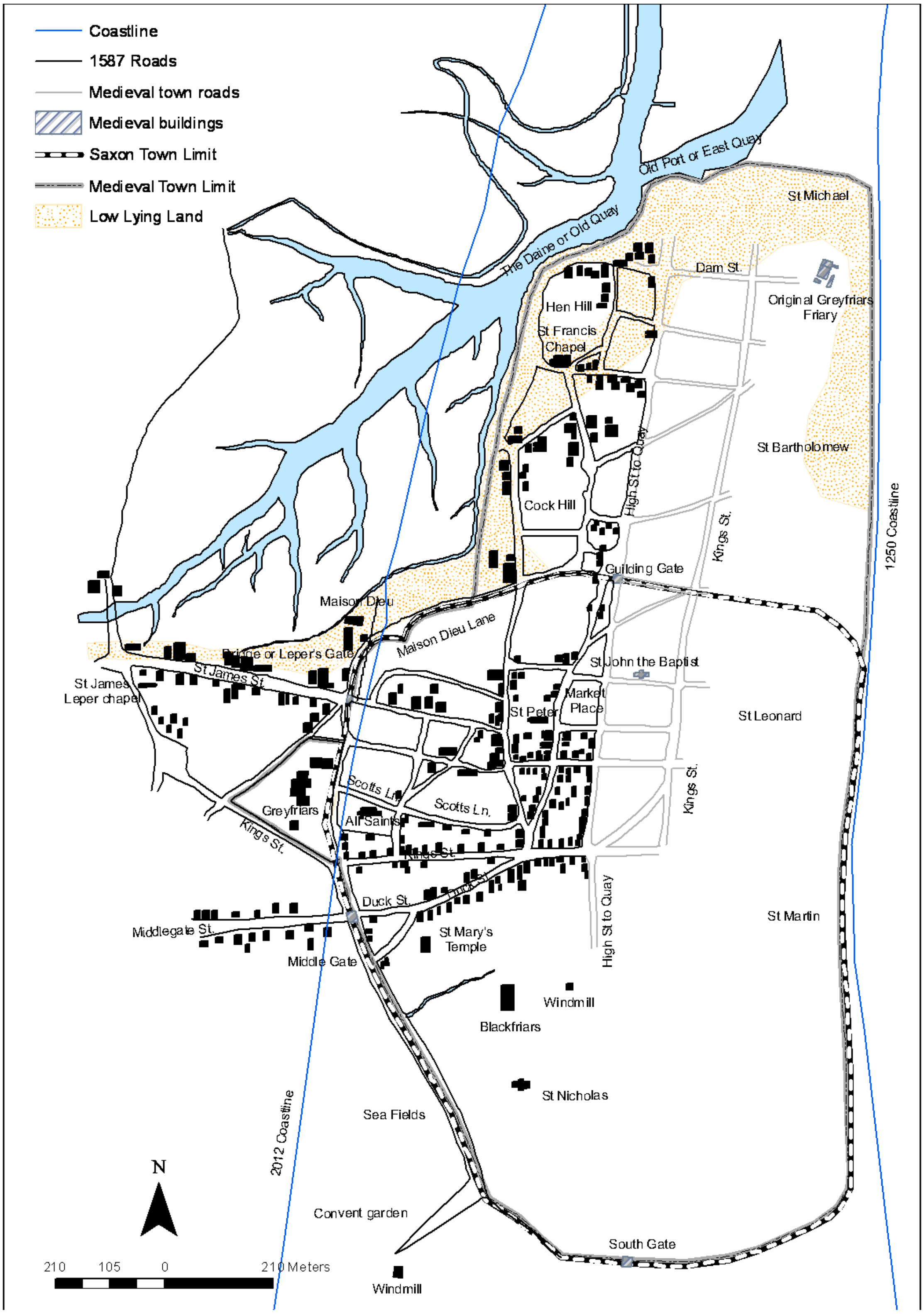


Figure 50 Reconstruction of the Town of Dunwich based on documentary, map and coastal change analysis. The Saxon town limits are speculative but assume a Saxon date for the Pales dyke (Time Team 2011), and its extension to the north and east along the contour line. Lower lying ground to the north is confirmed by coastal pilot charts, the 1587 map, and current topography. The lower lying areas were therefore susceptible to inundation, burial by sand and gravels, and scour in addition to cliff retreat.

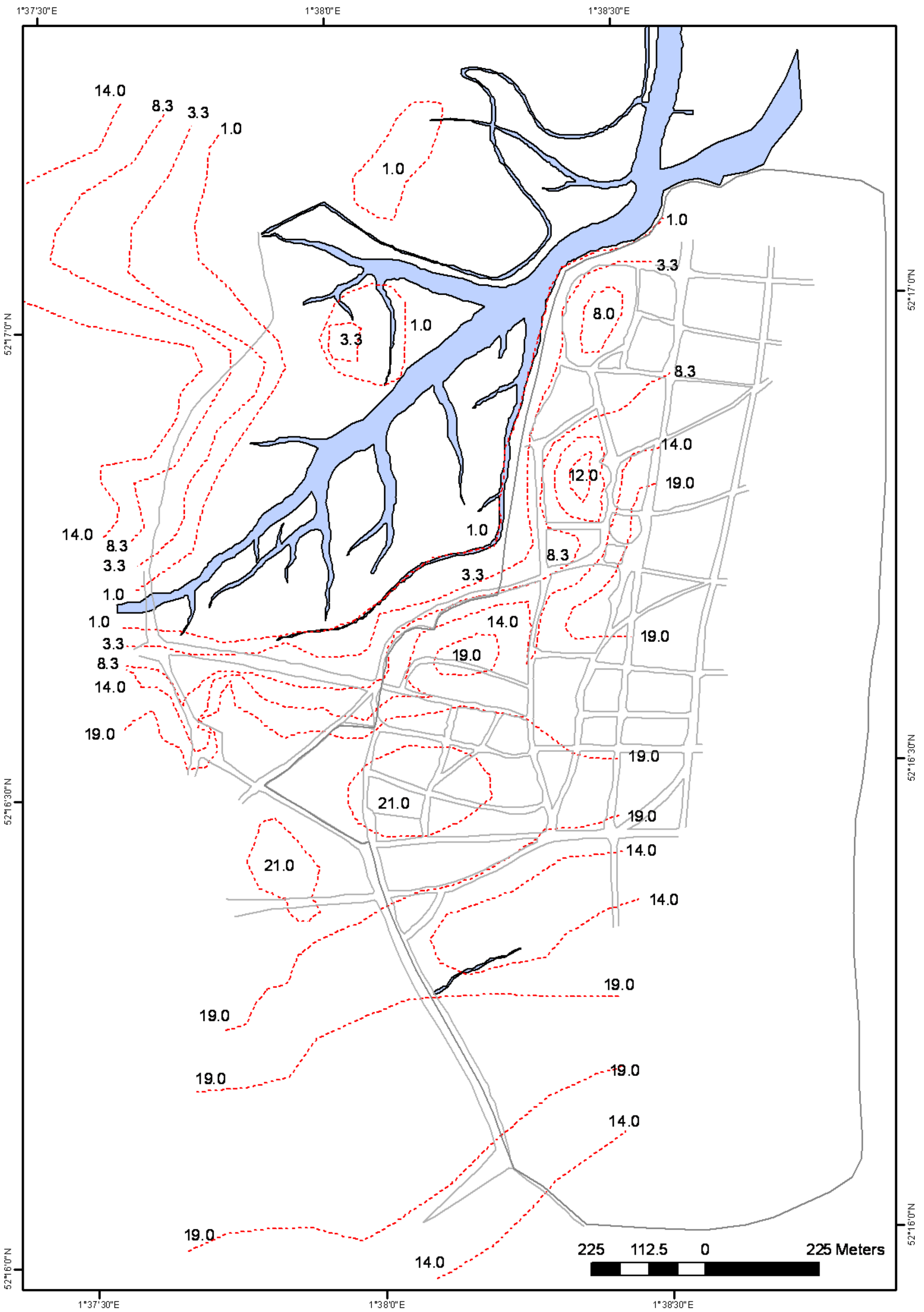


Figure 51 Topographic reconstruction of the town at the time of Agas, based on 17th Century Pilot charts, the 1587 Agas map, documentary references and artistic and photographic sources post 1800 and EA LiDAR flown in 2005).

7.9.6 We combined the data from the Pilot charts, Environment Agency LiDAR 2m raster data (EA 2003) and information from paintings and photographs from the 18^{th} – 20^{th} century with the topography and road alignments in the 1587 Agas map to reconstruct a plausible topography for the town up to 1587 (Figure 52). This highlights that lower lying areas around the harbour, but also suggests that some of the main roads were aligned along the shallow valleys see in the cliffs in 1637 and 1671. This would correspond with the current situation for Bridge Gate (St James Street) and Middlegate street which traverse the lower lying areas in the current cliff line.

7.9.7 The reconstructions show that for much of the coastline, there would have been an eroding soft cliff line. The highest cliffs were in the middle of the town getting lower seaward of All Saint's church, and to the north. Most property in the north was located on land above 3m, though this was not removed from inundation during storm surges (Pye and Blott, 2006).

7.9.8 The topography of the town east of the Agas map is unknown. However, by combining the records of the sequence and timing of damage reported between 1250 -1331 (Gardner, 1754, Confort 1994; Sear et al 2011) with the hindcast estimates for shoreline changes in the same period (83 years), it is possible to define the most probable areas of lower lying land (Figure 51).

7.9.9 The LiDAR 2m data clearly shows the presence of two low lying islands (gravel cored?) in the Dunwich river estuary (Figure 51). Birks (2003) has demonstrated the importance islands within saltmarsh or estuary landscapes. Their relationship to the town and their archaeology remain unknown.

7.9.10 The records reported in Gardner (1754) indicate that the first Churches lost were those of St Michaels and St Bartholomew's. No records of their parishes are found after 1331. Notably, the patronage of St Michael is for Mariners, boatmen and danger at sea. Moreover, Michaelmas marks the start of the herring fishing season. These all point towards a position close to the port facilities around the harbour in the lowest lying area of the town. This parish and associated buildings would have been subject to flood inundation and scour, burial by sands and gravels washed over the land surface during storms surges, and coastal retreat.

7.9.11 Little is know of the church and Parish of St Bartholomew. St Bartholomew is the patron Saint of Leather workers, tanners, butchers and whiteners; all industries associated with noxious smells. Traditionally, these industries were placed in the east of settlements away from the main markets. Whilst speculative, the association with such industry and the early loss probably places the parish and church of St Bartholomew in the north east of the town, on lower lying ground south of the first Greyfriars site and the parish of St Michaels. This lower lying area is akin to the situation reported for Winchelsea which was also inundated and destroyed by storms over the 13th Century (Eddison 1998).

7.9.12 The Third Church to be lost was St Martins. It must have survived the storms of 1328 since the last Rector was invested in 1335, however in 1334 the parish was down to 34 tax-payers and by 1342 only seven houses remained (Comfort 1994). Unlike the previous churches, the remains of the Parish lasted into the 15th century. In 1407 common land in the parish of St Martins was being used to dry fishing nets, and in 1408 some land in the Parish was given to the Temple. The coastal location (fishing nets) identifies the location of the parish in the east of the town. Although lost early, survival of remnants of the parish into the 15th Century suggest an eastern position stretching landwards into higher land (Figure 51).

7.9.13 St Leonards Church and parish included a Chapel of the Hospitallers of St John and the King's Street, which stretched westwards from the original site of Greyfriars to the Daine (harbour) Gardner 1754). Comfort (1994) has interpreted this to mean that the parish was located in the north of the town, but King's Street enters the town in the central area and must thus have turned north, running through the town centre towards the quays before turning west to the Daine (harbour). The Church is mentioned in 1220, and in 1334 the Parish had 34 houses within it. The Church was providing the Priory of Eye with its due, as late as 1342, and must therefore have survived the storms of 1286/7 and 1328. However it is not mentioned thereafter, although a hose within the Parish existed up until 1450. Like St Martin's the parish and Church must have occupied an area in the east of the town, stretching west into areas of higher ground that survived the storms of the 13th and 14th centuries.

7.9.14 The cruciform church of St Nicholas presents the first real anomaly between the records, mapping and field evidence. The parish was large (300 houses) and wealthy, but by 1334 only 42 tax-payers were listed, and by 1342 the parish had only 18 houses. According to Gardner (1754) who based his account on existing town records, the Church of St Nicholas was closed after the last incumbent was invested in 1352, which probably gives a data of around 1380 at the latest. It was stripped of all its valuables and left ruined. We know that two the west of the churchyard lay a 4 acre field, and that its land was joined to those of Blackfriar's.

7.9.15 The last portion of the churchyard was lost in the great storm of 1740 (Gardner 1754). The position of St Nicholas Church is described in Gardner (1754) as lying 20 Rods (c.100m) Southeast of Blackfriars. The geophysical surveys undertaken at the site have confirmed a building in this vicinity (Sear et al., 2011) which if the site of St Nicholas Church would mean that its ruins were lost sometime c. 1700 rather than that suggested by others as sometime in the mid fifteenth century (Bacon & Bacon 1979; Comfort 1994). The absence of any ruins in the Agas 1587 map or any description by Gardner in 1754, suggests that the site was overgrown and largely buried beneath the surface similar to that reported for the site of St Francis Chapel (Gardner 1754) and Greyfriars friary (Wessex Archaeology 2012). Investigation of the seabed ruins of should be undertaken to confirm the presence of materials from a church building. The balance of probability is that the Parish declined early following losses in the storms and plagues of the 14th century. Economic decline perhaps led to rationalisation of the town into the central remaining parishes (St Peter, St John, All Saints). Certainly the 1587 Agas map shows the southern half of the town to be largely open space which might support the concept of such a rationalisation.

7.9.16 The cruciform church of St John the Baptist lay opposite the Market place east of St Peter's church. The parish is stated as including Blackfriars, but this might be the result of the loss of St Nicholas Church and a subsequent transfer of this parish to St John's. The Church survived the storms of 1286/7 and 1328 and it was not until c.1510 when concern was first raised about encroachment by the sea. The Parish did not suffer the same losses (if at all) as St Nicholas, St Leonards and St Martin's and became by 1334 the largest and wealthiest of the Dunwich parishes with 91 taxable properties. It was alone with St Leonard's in being able to fulfil its quota to the Monks of Eye after the 1331 storm. St John's gained a rector after 1352 when St Nicholas closed.

7.9.17 The Church was under threat from erosion by 1542 and a pier was built to protect it and the town, and replaced again in 1544. Around c.1550 the church was pulled down and stripped of all valuables. At sometime later the ruins were lost to the sea. St John's is not shown on the Agas map drawn some 30-40 years later. St John's represents the demise of the first of the central parishes located on the higher land, and as such was lost some 200 years after the previous churches (excepting St Nicholas). It's location is suggested in Figure 51, opposite the market place and in the vicinity of some possible ruins, currently buried under sand.

7.9.18 St Peter's church is the first of the large buildings shown on the Agas map of 1587 and whose loss is documented. The church was founded by 1175 and may have been one of the three churches mentioned in the Domesday survey. It was described as almost as long as Blythburgh, and simple – a tower, nave and chancel, with no aisles. St Peter's was never a wealthy parish (34 taxable properties in 1334) and despite surviving the storms of 1286/7 and 1328 it sustained gale damage (Comfort 1994). Its chancel was rebuilt and possibly extended in 1512 (when St John's was considering spending money on coastal defences). In 1540, the church sold some of its goods to keep the harbour in good repair. Like many of Dunwich's churches, the last service was held in 1654/55, some 30 years before the building was lost to coastal erosion. St Peter's tower remained a landmark to shipping along with All Saint's until c. 1671 (see Seller's coastal pilot chart 1671). The east end of the church collapsed down the cliff in 1695, with the tower going in c.1702 (Gardner 1754). The churchyard lasted until 1734.

7.9.19 The last of the medieval Dunwich churches was that of All Saints, whose tower finally collapsed down the cliff in 1921. All Saints Parish was not wealthy, but it was old, being listed in 1175. All Saints benefited from the losses of St John's and St Peter's. A new north aisle was added in 1537 when St John's was closed and on the cliff edge. With the loss of St Peter's, All Saints become Dunwich's only parish church. It took c.210 years between the loss of St Peter's in 1702, and the loss of All Saints in 1921, but again the last service was held in the latter, some 125 years before the building was eventually destroyed. The ruins of the church are known to exist on the seabed (Bacon & Bacon 1979) and became an icon for the lost Town of Dunwich. The Parish of All Saint's may have been quite small, and occupied the northwest corner of the main town, with relatively few taxable properties given its situation away from the central market place. The ruins have been identified by Stuart Bacon, and lie under the first sand bank, gully and the beach.

7.9.20 Blackfriars or the Friary of the Dominicans was established in c.1256 and was enlarged in 1349 (Comfort 1994). It was described as a walled and gated precinct containing a church and associated buildings (Gardner 1754). The Agas map of 1587 shows a ruin with bays, located 442m SSE of All Saints Church. Gardner (1754) refers to its location as 120 rods (605m) southeast of Greyfriars which is close to the location recorded by Agas. The records report that by 1385 the sea was getting close to its perimeter, but in 1413 it was given the churchyard of St Nicholas, and was still functioning when it was abolished in 1538. The coastal change analysis does not support this, as in 1385 we predict the coastline to be 586m from the Blackfriars ruins, and the 1587 Agas map shows the coastline to be 186m east of these ruins. This would suggest a massive enclosed precinct, which while perhaps explaining the large area without housing on the Agas map, would not explain the lack of property within the adjacent St Nicholas parish. In any case, we have a position located on the Agas map, which is assumed to be the main buildings. The date of 1717 for the loss of the last buildings of Blackfriars corresponds with the coastal change analysis.

7.9.21 The Town of Dunwich was protected at least to the south and west by a defensive ditch and bank surmounted by a wooden palisade, called the Pales Dyke. The Pales Dyke was pierced by at least 2 gates in the west (Bridge gate where St James street entered the town, Middle gate where Middle gate street entered. In the south we know of the South gate which was lost in 1570. Analysis of the time series of coastal erosion points to the probable position of Guilding Gate in the north of the town (this gate was mentioned as damaged at the same time as South gate was lost). A "seagate" separating the northern lower lying part of the town from the commercial and trading entre within the Pales dyke on the higher land where the main road from the harbour entered the limits of the main town (former Saxon burgh?) is consistent with other ports of this age (e.g. Ipswich, Southampton; Barley, 1976). It also seems unlikely that the defensive ditch did not extend round to the east, since the coast was not in close proximity to the town prior to 1250AD. Early records refer to an "Eastwood" and the loss of 2 carracutes of farmland prior to 1089AD, suggesting a reasonable area of land existed between the town margin and the coast to the east. Coastal hindcast projections, uncertain as they are, support this view. Moreover, it would be unlikely that the town would have developed at all were the position not to have been considered a safe location and investment (though see the example of Winchelsea in Eddison 1998).

7.9.22 Whilst some elements must remain conjectural (e.g. Saxon town limits, position of the first Greyfriars site, parish locations east of the Agas map), Figure 50 represents the most accurate map of Dunwich to date. The northern limit is bounded by the Dunwich / Blyth river, whilst the eastern extent is set by the erosion rate evidence and documentary evidence for the physical loss of buildings. The southern limits are set by the bounding to the east, and the curvature of the Pales Dyke shown on the Agas map.

7.9.23 Despite the relative accuracy of the reconstruction, the boundary of the site should not solely be based on the medieval town limits. There are sites of archaeological and heritage interest located outside of the main town boundary. These include the Norman leper chapel of St James, the Georgian church of St James, the archaeology underlying and bordering the main streets leading to the medieval town, and sites such as the Leat Hill. In addition, there is reason to consider maritime archaeological heritage exists within the former Dunwich river estuary, particularly on the margin with the former medieval town and northern properties bordering St James Street.

7.9.24 The estuary of the Dunwich/Blyth contains a record and features associated with the long history of drainage and flood protection, as well as ditch and bank systems associated with medieval and later ownership of the marshes. Furthermore, studies conducted in Westwood marshes to the north (Brew et al 1993) and Minsmere marshes to the south (Lloyd et al., 2010), reveal the value of the sedimentary records that document the pollen history of land use in the area, as well as the sequences of marine transgression and regression. Recent undergraduate dissertation projects (Geography, University of Southampton) have shown that the marsh sediments record a long term history of coastal storm events dating back over the past 500+ years.

8 PROJECT SUMMARY

8.1.1 The overall results of the project can be summarised as follows:

1. The Dunwich Town site comprises a range of different heritage, in the form of archaeological remains (marine and land-based), historic documents and spatial data (maps, charts etc.), and sediment archives. Collectively they help define the history and extent of the town, and its significance as an international port and trading centre, and as a significant centre of religious life. It represents the only site in UK waters where medieval buildings of known identity have been located and recorded.

2. The evidence assembled in this project has enabled a reconstruction of the probable limits of the town. These reveal that it was substantial urban centre, occupying an area of c.1.8 km^2 with a central area enclosed by a defensive (Saxon?) earthwork of c.1.1km^2. Within these limits are the ruins or sites of 10 of the documented buildings of medieval Dunwich. Of these Greyfriars Friary, St James Leper chapel and Maison Dieu hospital and chapel(?) are located on land. The churches of All Saints, St Peter and St Nicholas are identified and positions known. The site of the Church of St Mary, Knights Templar is known, as is the chapel of St Francis, but both are buried under the first sand bank, and are currently undetectable using current geophysics. The location and probable ruins of Blackfriars Friary and the Chapel of St Katherine are identified. In addition, we have identified additional ruins that initial interpretation suggests is part of a large house, possibly the town hall.

3. We have found very little evidence of ruins or structures associated with the northern area of the site towards the former harbour. Some evidence exists for a scattering of small sites, but none are of the scale or characteristics of the ruins of larger stone buildings found at the site. This suggests that for the northern area currently exposed between the inner sandbank and Dunwich bank, there is no evidence for the presence of larger stone buildings. This is in keeping with the view that this area was largely commercial and linked to the harbour, with buildings and harbour structures typically built of wood. We have not found any evidence of the “walls” observed by Gardner following the 1740 storms which he linked to former harbour walls. We deduce from this that these lie under the first sand bank. We also conclude that any former stone structures (the Churches of St John, St Leonard, St Marton, St Michael and St Bartholomew, the Chapel of St Anthony and the former site of GreyFriars), all lie under the western edge of the Dunwich bank, and are currently undetectable using geophysics. It is possible that the five magnetic anomalies located within the town boundary east of the 1587 Agas map limit are associated with some of these earlier structures.

4. The Geophyscial survey data has identified the former course of the Dunwich river and has enabled us to extend the AGAS 1587 mapped limits for the river to demarcate the northern extent of the town. The

position and width of the river are confirmed by palaeochannels visible in Boomer and Parametric sub-bottom profiles, the presence of a tongue of estuarine clay and marsh peat (?) visible in Sidescan data, and a shallow trough visible in MBES data from 2012. These data coincide with the line of the former “old port” on the Agas map, and show that Dunwich/Blyth river extended north east across the top of the town (Figure 50).

5. Historical change analysis using all applicable historical coastline data has enabled us to hind-cast the position of the coastline. Uncertainty in the locations is low in model terms (ie the model fits the existing data well for the earlier dates) but remains unknown in terms of the changes in coastal process rates earlier than 1587. However, the position of the coastline at the time of the first major loss of buildings recorded at Dunwich c. 1286-1328 results in a realistic size of urban area for a town of the time.

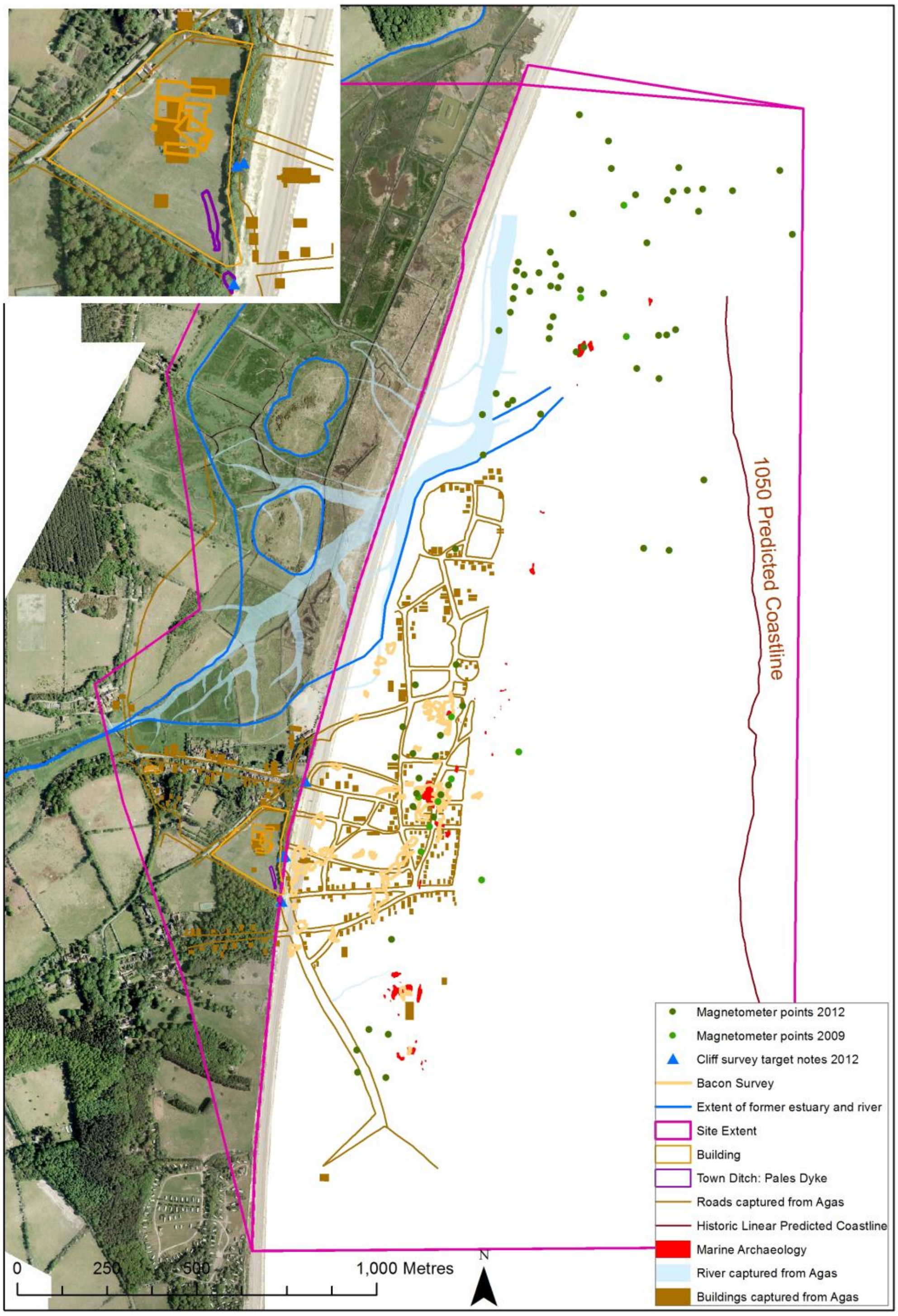


Figure 52 Synthesis of archaeological data available for the Dunwich Town site. Blue triangles denote the site of Lepers (Bridge) gate and St James street (north), The last remaining gravestones in All Saint's churchyard (centre) and the exposure of the Pales Dyke cross-section in the cliff (south). Magnetic anomalies cluster around the former centre of the town, and in the area of the former Kingsholme, north of the Dunwich river. The latter is considered to reflect gunnery practice during WWI and WWII. Notably there is little evidence of magnetic anomalies in the northern and eastern sections of the town.

6. Contemporary forecasts of coastline position were modelled using data post 1904, and found to result in high model uncertainty (±53m). Nevertheless, the results are considered to reflect the realistic extent of erosion for 2050 and 2080 assuming beach, cliff and wave regime remain within the variability used in the model.

7. Documentary, artistic, photographic, LiDAR and historic Pilot chart data back to 1631 and c.1570 confirms the presence of cliffs along most of the town, and a lower lying section in the north towards the harbour. This has enabled us to reconstruct a plausible topography for the site back to 1587. This indicates that the cliffs, though lower than currently, were still c. 14-19m high. As a result we can conclude that all the confirmed ruined sites discovered to date collapsed over a cliff prior to entry into the littoral zone. Moreover, this is likely to be the case for most of the other lost church sites, with the possible exception of St Michaels and St Bartholomew, whose early loss points to a northeast location on lower lying land near the harbour.

8. We have been able to conclude that all the major ruins identified on the seabed went through a similar process of; abandonment, partial or complete demolition, progressive collapse down a cliff, and progressive passage through the beach and inner sand bank until exposure in the trough between the inner and Dunwich sand banks. Most of these visible structures have had a similar period of time within the littoral zone, but have had different periods of time as a land-based ruin. We have found that the area and size of the ruined materials correlates with the size and scale of the buildings. Church ruins cover larger areas and have larger blocks associated with the remains of towers.

9. We have as a result of the data synthesis and analysis of coastal and bathymetric change, been able to identify sites at risk from erosion of the cliff and burial by sand banks. We list 6-14 sites at risk to cliff retreat between 2050 and 2100. Bathymetric change analysis reveals a much more complex and therefore unpredictable pattern of scour and accumulation around ruins on the seabed. The result has been periods of burial and exposure of the ruins over time controlled by the growth of offshore sandbanks and changes in near shore bathymetry resulting from cliff erosion. The main risk to the marine ruins are identified as attrition from mobile sand and smaller gravels, (though the preservation of structures some 330 years after entry into the littoral zone suggests that this is process is relatively ineffective), but primarily from the activity of fishing trawls and divers, particularly now the site is well documented.

8.2 EXTENT OF SITE

8.2.1 The project set out to compile and map the available evidence on the Dunwich Town site in order to help define the area over which it extended, and to determine the nature of the heritage within that space. We have reconstructed the most plausible limits to the town using the best available methods, and have mapped the available information on heritage and archaeology. Definition of the boundaries to the site is contestable. We have specifically included within our definition, the area of the former town together with its estuary; and refer to this as the Dunwich Town and harbour site. This recognises explicitly the importance of the sedimentary archives within the estuary, the potential for maritime and estuarine archaeology in these sediments, and the potential for archaeology on the two low lying gravel islands identified within the estuary. Birks (2003) highlights the importance of islands in estuary/saltmarshes. To date there has been no investigation of these features at Dunwich, though thre is evidence of earthworks and possible ridge and Furrow field systems (Good & Plouviez 2003).

8.2.2 Figures 53 & 54 present an interpretation of the boundary of the Dunwich Town and harbour complex. It does not include any of the heritage features associated with the hamlet of Dingle on the west of the former estuary, although an argument for including this can be made. Neither does it include the northern sections of the former Dunwich/Blyth River that are still extant in the Westwood and Walberswick marshes.

8.2.3 The western boundary margin is contestable; at present it incorporates the features shown on the Agas map, but does not include any outlying farms or field systems. The definition of this boundary could be improved by a combined landscape and field walking archaeological survey.

8.2.4 The Northern boundary to the site is defined by a) the extent of magnetometer targets, and b) by uncertainty over the precise course of the former Dunwich river in the northeast. The boundary as shown includes the possibility that the harbour and northeast area of the town extended further north, though this is considered unlikely. Contemporary examples of estuaries with spits/gravel barriers on the Suffolk coast tend to push the estuary exit towards the south due to the dominance of the southerly drift direction, and the relative weakness of the fluvial processes.

8.2.5 The eastern boundary is broadly defined by the predicted coastline position c. 1000AD and the most easterly magnetometer targets. The data of 1000AD was selected simply because the Domesday entry for Dunwich records a community with a single church during the reign of Edward (1042 – 1066), and at the time of the survey, 3 Churches

(1089). Whilst the settlement referred to is assumed to be located within the extent of the medieval town, we have extended the boundary to include any possible archaeology particularly in the north east where the estuary may have had harbour and fishing associated heritage. An alternative position for the eastern boundary is further west, along the predicted coastline in c.1250AD which would include the medieval town.

8.2.6 The southern boundary is defined by the curve of the Pales Dyke shown on the 1587 Agas map, which we extended south by 200m to include uncertainty in its position.

8.2.7 In summary, the boundaries proposed for the site are contestable. Additional field and landscape survey is required to establish the western margin. Alternatives to the eastern boundary could be justified. However, these provide an initial area that might be proposed for designation for the protection of the archaeological and heritage associated with the Dunwich town site.

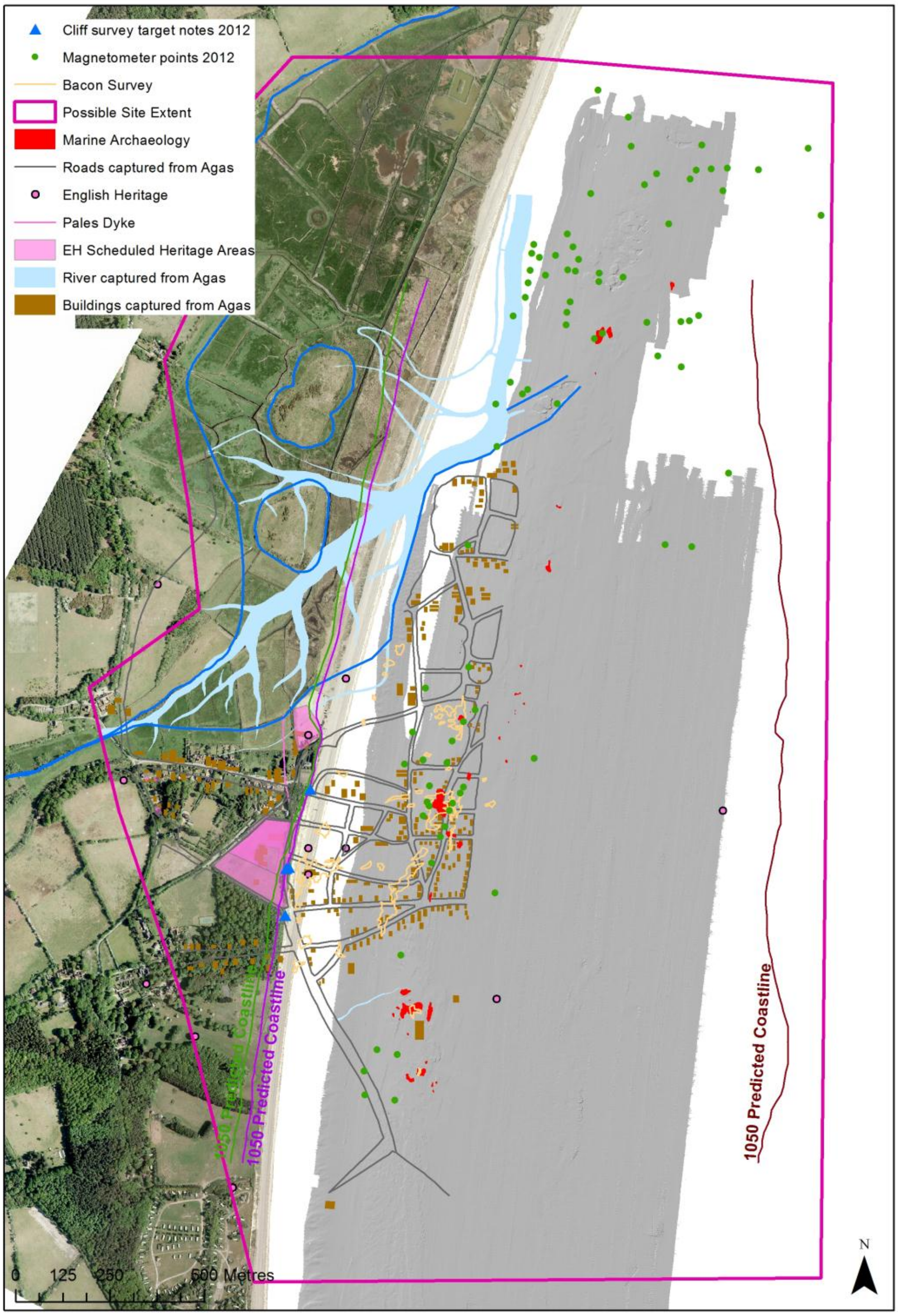


Figure 53 A suggested boundary of the Dunwich Town and harbour site. The eastern boundary is extended beyond the medieval coastline to include any possible archaeology associated with the early origins of the town. It might equally be set to the predicted medieval town limits. See text for additional explanation.

8.3 Evaluation of approach

8.3.1 The methodology adopted for the definition of the boundaries of the Dunwich Town site and the evaluation of risk to extant heritage has:

1) Defined the range of different heritage features on both land and in the littoral zone
2) Applied and evaluated a suite of marine geophysical surveying technologies in terms of their ability to locate, quantify and identify archaeological features from the medieval town of Dunwich.
3) Undertaken geomorphological analysis of cliff retreat and littoral morphodynamics to understand the risk to heritage features identified in (1) and (2).
4) Collated and interpreted a range of historical documents, maps, charts and pictures/photography to (i) define the processes resulting in the formation of the marine heritage, (ii) define the geography of the medieval town, (iii) to reconstruct the topography of the site, and (iv) understand cliff erosion mechanisms and sequencing.
5) Used GIS based mapping to synthesize all the data captured in (1-5) to reconstruct a plausible geography, topography and historical narrative for the Dunwich town site, and used this to understand the condition of the marine heritage features and the risks to existing heritage from coastal processes.

8.3.2 The methodology demands allocating geospatial data to all relevant attributes, and whilst this was more successful than envisaged (re Agas Map), this proved particularly problematic with early coastal charts, estate maps and pilot book views of the coastline. For example, during the project a previously unknown map of the cliff line was discovered by Kath Chant (Dunwich Museum) in the records of Downing College Cambridge (the Downing family owned the Dunwich estate in the 18th century). This was dated to c. 1772 and thus filed a gap between the 1753 coastline of Gardner (1754) and the Tithe map of 1826. Unfortunately, the cartography of this map was so poor that it proved impossible to georectify with an acceptable degree of accuracy. It did however, provide qualitative information on the location of buildings at that time.

8.3.3 The use of historic paintings, sketches and photographs were valuable for reconstructing the processes of cliff retreat (emphasizing the relationship between periods of rapid recession and the absence of a beach), topography and the process by which land-based heritage transitions to marine heritage. In the latter, the effects of abandonment and robbing of a building emphasizes how much (in the case of All Saints church) or how little (in the case of Maison Dieu or Greyfriars) can be left, and what the effects of cliff collapse are on the size, characteristics and type of ruins. Together they helped with the identification and interpretation of the marine archaeology.

8.3.4 The Suite of geophysical surveys used in this project show for the first time, the utility of integrating broad scale Multibeam and Sidescan sonar data with high resolution DIDSON acoustic imaging. Our evaluation demonstrates the need for nested scales of geophysical survey conducted at increasing data capture resolution. Experience at Dunwich showed that combined MBES and Sidescan Sonar, captured at 10cm resolution was sufficient to locate most archaeological features and to permit repeatable mapping of individual sites. It did not permit identification of the sites in the first instance, but was able to support hypothesis based estimates of probable archaeological remains (e.g. block fields from larger buildings).

8.3.5 The DIDSON-DH system provides additional data for a) mapping the immediate site environment, b) detecting the presence of marine life at a site, c) identifying worked stone from rubble structures, c) defining the type of archaeology present at a site (stone accumulations, rubble blocks, cut stone), and (d) differentiating between archaeology and natural rock outcrops. It is this a valuable tool for identification of specific features and confirmation of the type of archaeology present. However, the DIDSON-DH resulted in significant data redundancy and lacked geospatial referencing. We have demonstrated that by combining high resolution MBES or Sidescan data with DIDSON sweeps, it is possible to generate higher resolution mosaics of a site through post-processing. Nevertheless, we recommend that in future applications, the DIDSON is deployed in two specific contexts; first, as a tool for site investigation and identification as undertaken in this project and secondly in scanning mode when deployed from a platform of known position (ROV or fixed survey point). The experience from our initial sweep surveys suggest that deployment from an ROV is probably better, and tests to optimise the angle of insonifcation over a site should ideally be conducted in order to reduce obscuration by acoustic shadowing.

8.3.6 Although not totally necessary in that useful data can be captured after a short training session onsite, the high data redundancy highlights the need for training in DIDSON-DH as a means of optimising time on site. Training in the DIDSON-DH should initially be conducted under controlled conditions (e.g. a large pool or lake) and include both feature location and feature identification. Within the latter this should include a controlled application of the different range settings to familiarize the divers with this function and its limitations. Training should then ideally switch to the site so that the divers can experience the operation of the DIDSON-DH under conditions including waves, tidal currents and the specific site conditions. The former affects the smooth lateral movement of the DIDSON-DH in much the same manner as high wind affects video filming.

8.4 FURTHER ANALYSIS

8.4.1 The project has identified areas for further survey and research that have site specific and more general relevance. Acoustic imaging technology has already advanced since release of the DIDSON-DH and DIDSON systems. The new Soundmetrics ARIS system, is a 3MHz acoustic imaging camera that is deployed from fixed mounts (ROV etc.): the system is capable of imaging at centimetre (15m range) to sub-centimetre resolution (5m range) providing higher resolution data than DIDSON-DH. The Teledyne Blueview™ 3D imaging sonar provides laser-scanning type 3D bathymetry over ranges of 30-10m suitable for rapid high resolution imaging of sites. Data is compatible with Leica Cyclone™ software for point cloud and mesh building enabling 3D visualisation. These systems operate in turbid environments, but in the case of the Teledyne Blueview™ 3D imaging sonar, requires a tripod or solid platform for deployment.

8.4.2 Specific research/surveys should include in order of priority:

Marine heritage

1. DIDSON/Diver based exploration of new sites identified in the 2012 survey. Specifically, sites to the east of the 1587 Agas map limits (24, 25, 27, 28, 30), and the new sites (3, 4, 13-15, 18, 53). Sites 3 and 4 in particular require investigation as the potential to be the Tollhouse or Town hall, or gaol.
2. High resolution ARIS identification surveys or visual diver surveys of the St Nicholas church site, and St Katherine Chapel site to confirm / establish the nature of the ruins.
3. Evaluation of the archaeological value of using ARIS / Teledyne Blueview™ 3D imaging sonar data deployed from fixed or position fixing (ROV) platforms. Such an evaluation should include tests with known objects placed on the seabed, a wreck site(s) and building structures such as those found at Dunwich. Evaluation should focus on optimising deployment angles, resolution and beam geometry for identification of different types of archaeological material, and for evaluation of heritage deterioration. The ARIS and Teledyne Blueview™ 3D imaging sonar systems should be evaluated independently of each other and in conjunction to determine optimum benefit for archaeological survey.

Land-Based

1. Conduct as a matter of urgency, an archaeological survey to establish the earliest date for the construction of the Dunwich Town Pales Dyke defences. This should include excavation of a) Bridge (Leper's) Gate site on St James Street, to establish the nature of the last remaining gate into the medieval town, b) Survey and recovery of dateable (Luminescence /C_{14} /Pottery dating)materials from the bottom of the exposed cliff section through the Pales Dyke, and c) survey and

recovery of dateable material (Luminescence /C_{14} /Pottery dating) from the cliff exposures of St James Street, MiddleGate street and Scotts Lane and the un-named lane north of All Saint's churchyard.
2. Conduct a geophysical and ditch survey of the land-estuary interface bordering the Maison Dieu site (OCN SF142), and along a line north of St James street to confirm, record and date the possible wharfage and maritime infrastructure in this area.
3. Conduct an archaeological and geophysical survey of the two islands located in the Dunwich river estuary.
4. Undertake a geophysical and limited archaeological survey of the land adjacent to Middlegate street to determine the extent and date of urban expansion west of the former limits of the medieval town.
5. Undertake palaeoenvironmental analysis of the Dunwich river estuary sediments in order to; (i) reconstruct the history of storm wash over events over the past millennium, (ii) reconstruct the history and timing of the transition from open estuary to freshwater marsh between 1000 – 1800AD, and (iii) reconstruct the environmental history of the Dunwich river to determine the sequence, type and magnitude of changes associated with different settlement phases at Dunwich.
6. Commission and publish an authoritative account of the Dunwich Town site.
7. Conduct a field and aerial photographic survey to refine the western boundary of the archaeology associated with the medieval and earlier settlement(s) at Dunwich.

9 BIBLIOGRAPHY

Barley, M.W. (1976) The plans and topography of medieval towns in England and Wales, Council for British Archaeology, Research Report No. 14, Leamington. 91p.

Bates, C. R., Lawrence, M., Dean, M. and Robertson, P. (2011), Geophysical Methods for Wreck-Site Monitoring: the Rapid Archaeological Site Surveying and Evaluation (RASSE) programme. International Journal of Nautical Archaeology, 40: 404–416. doi: 10.1111/j.1095-9270.2010.00298.x

Birks, C., 2003. Report on Archaeological Evaluation at Blakeney Freshes, Cley-next-the-Sea, 37793 CLY, Norfolk Archaeological Unit Report 808 (revised). (Norwich)

Boulter, S and Everett, L., 2009, Dunwich Greyfriars: DUN 092 and 094. Archaeological recording works associated with the rebuilding of a section of the precinct wall and repairs to the gateways and Refectory, SCCAS report no. 2008/52; Oasis No. suffolkc1-57321, Suffolk County Council, 36pp.

Boulter, S. 2008, St James Leper Hospital, Dunwich (DUN 005, SM Suffolk 40); Building Recording Report, Suffolk County Council Archaeological Service Report No. 2008/180, Oasis No. suffolkc1-45624. Suffolk County Council, 29pp.

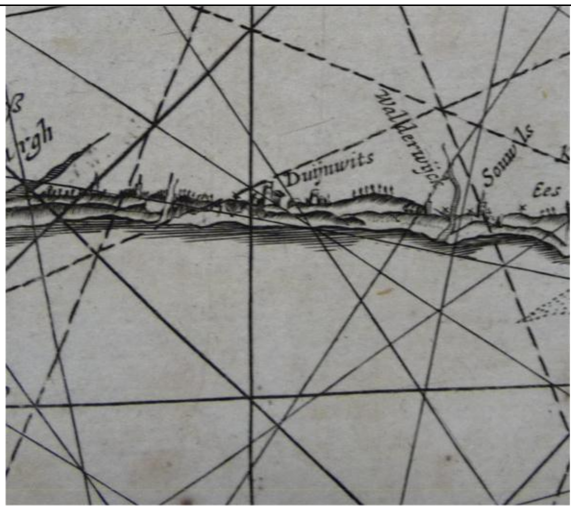
Brew, D.S.; Funnell, B.M., and Kreiser, A., (1992). Sedimentary environments and Holocene evolution of the lower Blyth estuary, Suffolk (England), and a comparison with other East Anglian coastal sequences. *Proceedings of the Geologists' Association,* 103, 57–74.

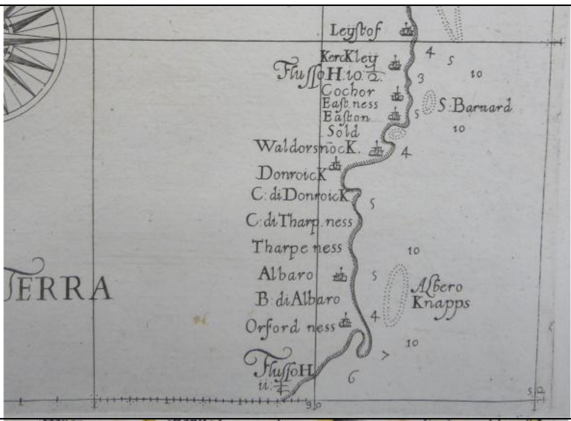
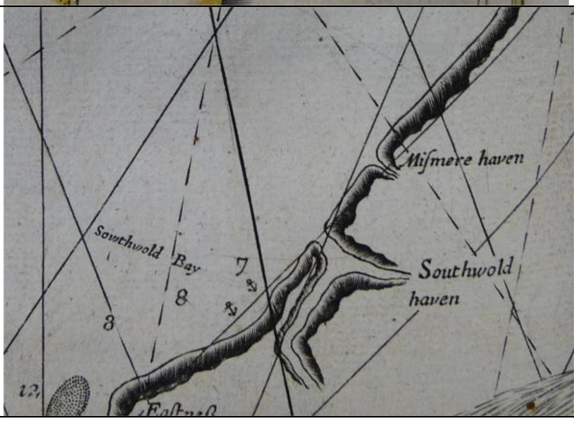
Brooks, S.M. and Spencer, T. (2010) Temporal and spatial variations in recession rates and sediment release from soft rock cliffs, Suffolk Coast, UK. Geomorphology 14, 26-41. DOI:10.1016/j.geomorph.2010.08.005.
Brooks, S.M. and Spencer, T. (2012) Shoreline retreat and sediment release in response to accelerating sea level rise: measuring and modelling cliffline dynamics on the Suffolk Coast, UK. Global and Planetary Change 80 - 81, 165 – 179. DOI: 10.1016/j.gloplacha.2011.10.008.
Brooks, S.M., Spencer, T., and Boreham, S. (2012) Mechanisms for cliff retreat in rapidly receding soft-rock cliffs: marine and terrestrial influences, Suffolk coast, U.K. Geomorphology, 153 – 154, 48 – 60. DOI: 10.0106/jgeomorph.2012.02.007.
Burrough P A and McDonnell R A 1998 Principles of geographic information systems Oxford University Press, Oxford
Cracknell, B.E. 2005, Outrageous Waves: Global warming and Coastal change in Britain through two thousand years, Phillimore, Chichester, UK, 302pp.
DCMS, 2007, Heritage Protection for the 21st Century, Department for Culture, Media and Sport, The Stationary Office Ltd, Norwich, 50p.
Defra (2010) Charting Progress 2: The state of UK Seas. Department for Environment Food and Rural Affairs, Nobel House,17 Smith Square, London SW1P 3JR . http://chartingprogress.defra.gov.uk accessed 01/2013
Dunkley, 2007, Protected Wreck Sites at Risk: A Risk Management Handbook (English Heritage).
EDF (2012) Sizewell C Stage 1 Environmental Report | November 2012, http://sizewell.edfenergyconsultation.info/wp-content/uploads/SzC-Stage-1-Environmental-Report.pdf
English Heritage 2006, MoRPHE Project Planning Note 1 Marine Geophysical Survey
English Heritage 2008, Geophysical Survey in Archaeological field Evaluation
Gardner, T., 1754, An historical account of Dunwich, ….Blithburgh, ... Southwold, ... with remarks on some places contiguous thereto, London, 291p.
Good & Plouviez (2007) Archaeology of the Suffolk Coast, Suffolk County Council Archaeological Service, Ipswich, Suffolk, UK.73p.
Haskoning 2009, Suffolk SMP2 Sub-cell 3c: Policy Development Zone 3 – Easton Broad to Dunwich Cliffs, Unpublished Report No. 9S4195/RPDZ3/301164/PBor, Haskoning, Peterborough, 57p.
Landmark Information Group (2002) – Landmark Information Group website.
Lloyd, J., Larcombe, P., Zong, Y., Woods, A., (2010) Relative Sea-level Changes and Coastal Evolution of the Minsmere Coastline, Suffolk, during the Late Holocene, unpublished poster, EDF-Sizewell.
McInnes, R. and Stubbings, H. 2010. 'Art as a tool in support of the understanding of coastal change in East Anglia'. The Crown Estate,92 pages. ISBN: 978-1-906410-10-0
Murphy, P., Thackray, D. & Wilson, E., 2009, Coastal Heritage and Climate Change in England: Assessing threats and priorities, Conservation and management of Archaeological Sites, 11, 1, 9-15.
Norris, N.E.S. (1936) 1st and 2nd report on excavations at Greyfriars monastery, Dunwich, July 1935 (& August 1936), Proc. Suffolk Institute for Archaeology, 22, pt.3, 287-289 & 290-293.

Norris, N.E.S. (1939) 3rd report on excavations at Greyfriars monastery, Dunwich, 1937-39, Proc. Suffolk Institute for Archaeology, 23, pt.3, 210-218.
Ordnance Survey (2004) The Positional accuracy improvement programme companion v1.0 Mar 2004.
Palmer, T. J., 2008, Identification of stones in the ruined medieval chapel of St Jame's Leper Hospital at Dunwich, Suffolk, unpublished Report to Simon Swann Conservators. 10p.
Pye, K., and Blott, S.J., 2009, Progressive Breakdown of a Gravel-Dominated Coastal Barrier, Dunwich–Walberswick, Suffolk, U.K.: Processes and Implications, Journal of Coastal Research, 25, (3), 589-602.
Quinn, R., 2006. The role of scour in shipwreck site formation processes and the preservation of wreck-associated scour signatures in the sedimentary record evidence from seabed and sub-surface data. Journal of Archaeological Science 33, 1419e1432.
Roberts and Trow 2002, Taking to the Water: English Heritage's initial policy for the management of maritime archaeology in England (English Heritage)
Robinson, A.H. W (1962) 'Marine Cartography in Britain' – a history of the sea chart to 1855.
The Royal Commission appointed to inquire into and to report on certain questions affecting Coast Erosion and the Reclamation of Tidal Lands in the United Kingdom (1907), Volume I, Lowestoft and Ipswich Record Offices: 551.36/Oversize/Stack.
Sear, D.A., Bacon,S.R., Murdock, A.P., Donaghue, G., Baggaley, P., Sera, C., and Lebas, T.P., 2011, Cartographic, geophysical and diver surveys of the medieval town site at Dunwich, Suffolk, England. International Journal of Nautical Archaeology, 40; 1, 113-132.
Sear, D.A., Bacon,S.R., Murdock, A.P., Donaghue, G., Lebas, T.P., 2008, Dunwich 2008 Project Report to Esmée Fairbairn Foundation, English Heritage & Dunwich Museum Trust, Unpublished GeoData Report No. UC1064, 58p.
Stansby, P., Cui-Ping Kuang, Laurence, D., Launder, B., 2006. Sandbanks for coastal protection: implications of sea-level rise. Part 1: Application to East Anglia. Tyndall centre for Climate Change Research, Working Paper 86. University of East Anglia, Norwich.
Taylor, J A; Murdock A P and Pontee N I (2004) A macroscale analysis of coastal steepening around the coast of England and Wales. The Geographical Journal , Vol. 170, No. 3, September 2004, pp. 179–188 Blackwell Publishing, Ltd.
United States Geological Service (208) Digital Shoreline Analysis System http://woodshole.er.usgs.gov/project-pages/dsas/).
Wessex Archaeology 2003, ALSF, Wrecks on the Seabed: Assessment, Evaluation and Recording, Year 1 Report.
Wessex Archaeology 2004, ALSF, Wrecks on the Seabed: Assessment, Evaluation and Recording, Year 2 Report.
Wessex Archaeology 2006, ALSF, Wrecks on the Seabed R2: Assessment, Evaluation and Recording, Year 1 Report.
Wessex Archaeology 2007, ALSF, Wrecks on the Seabed R2: Assessment, Evaluation and Recording, Year 2 Report.

Wessex Archaeology 2007, Wrecks on the seabed R2 Assessment, Evaluation and Recording, Unpublished Report 57454.03 to English Heritage, Wessex Archaeology, 29p.
Wessex Archaeology 2008, South East of England Designated Wrecks: Marine geophysical Survey and Interpretation.
Wessex Archaeology, 2010, East of England Designated Wrecks: Marine Geophysical Survey and Interpretation. Unpublished Report, Ref: 71770.02.
West, S. E. (1971) `The excavation of Dunwich town defences, 1970' Proc Suffolk Inst Archaeol 32(1), 25-37.
West, S.E., 1971, The excavation of Dunwich town defences, 1970 (with a note by N. Scarfe)' Proceedings of the Suffolk Institute of Archaeology and History Vol32 pt1 p25-37

APPENDIX 1.0 Historic mapping

Name	Author	Date	Description	Thumbnail
Speculum Orbis Terrarum *(Admiralty Library)*	***Gerard de Jode***	1578	Extract from this atlas shows Dunwich with churches, coastal morphology is represented rather differently around Orfordness	
Atlas *(Admiralty Library)*	***Gerardo Mercator***	1595	Extract from: Atlas, or a geographicke description of the regions, countries and kingdoms of the world: through Europe, Asia, Africa and America. Dunwich is shown with a church. *Note the graduation of 53^{o} north lies south of its true location and the longitude graduations which use a pre Greenwich central meridian.*	
The fierie sea-columne *(Admiralty Library)*	***Iacob Columne***	1637	*Wherein are shewed the seas, the sea coast of the northern, eastern and western navigation, manifestly inlightened, and the failings and mistakes of the former Light or sea-mirour amended*. Dunwich (“Duijnwits”) is shown with 2 square steepled churches and the coastline is represented to show the terrain. An unusual representation which combines the 2D plan form of a chart with the 3D representation of the coast as viewed from the sea. Note also the rhumb lines shown.	

Arcano del Mare *(Admiralty Library)*	***Sir Robert Dudley*** - *Dudley was an English chart maker operating from Italy*.	1661	This chart is from the unique Arcano del Mare which was the first sea atlas to cover the entire globe and had its own style which differed from other sea atlases of the period. Dunwich (labelled "Dunroick") is shown with a church. Southwold ("Sole") bay is also shown.	
Le grand atlas, ou Cosmographie Blaviane: en laquelle est exactement descritte la terre, la mer et le ciel. *(Admiralty Library)*	***Joan Blaeu***	1667	Map of Suffolk from the atlas. Dunwich (Labelled "Dunwiche") is shown again with a church and the Dunwich river is depicted flowing into Southwold harbour.	
The Coasting Pilot *(Admiralty Library)*	***John Seller***	1671	One of the many editions of this atlas. Dunwich not shown	

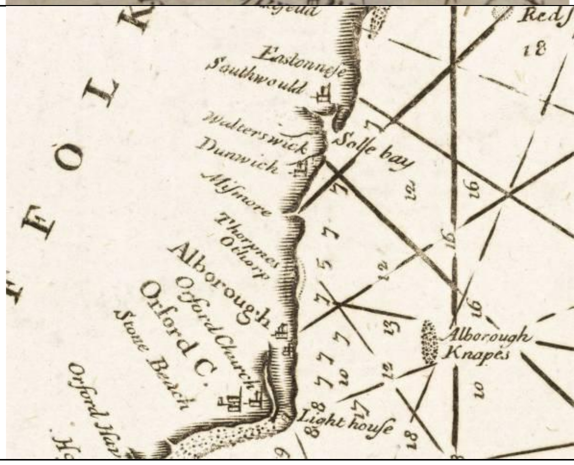
The English Pilot *(Admiralty Library)*	***John Seller***	1671 & 1708, 1715	This chart is from one of the many editions of the English Pilot and shows Dunwich with a church and also Southwold harbour. Bathymetric soundings are also shown, though too few to incorporate into the change analysis. This chart is duplicated in subsequent editions of which there were as many as 40, including some published after Seller's death.	
The Coasting Pilot *(University of Southampton Library, Admiralty Library)*	Greenville Collins	c. 1745, 1781	Chart extract from this sea atlas - Again there were several editions of this atlas but the work is based on Collin's surveys between 1682-1689. Again bathymetry and rhumb lines are shown but the scale too coarse to warrant georeferencing with this extract taken from a folded chart for the whole of the southern North sea.	

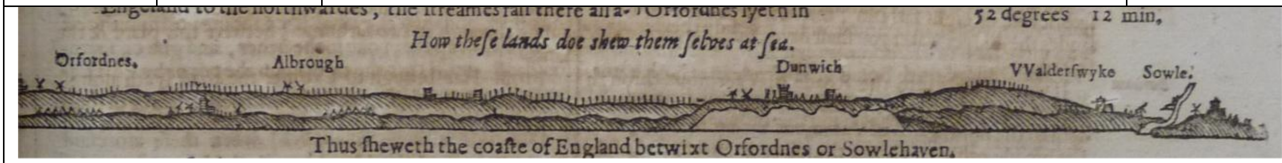
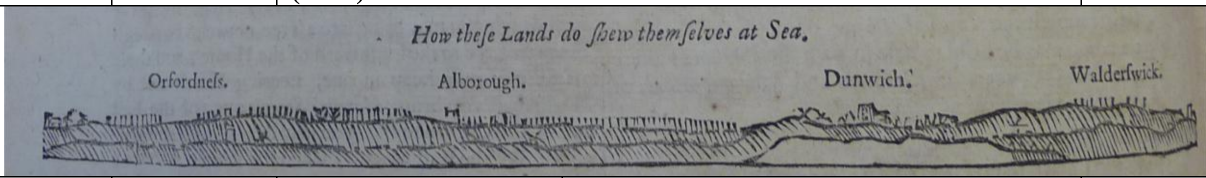
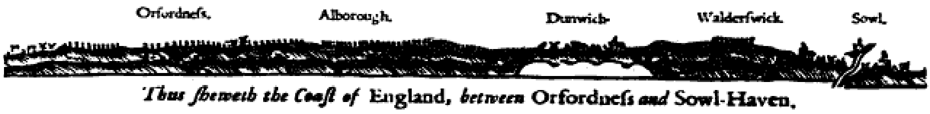
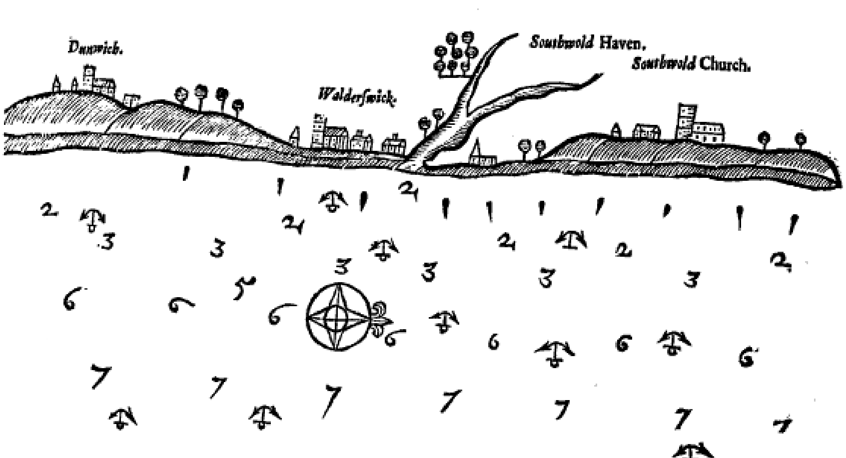
Table A1.1: Sample of available historical maps and charts

Date	Author	Source	Description	Location
1637	Columne	***The fierie sea-columne***	*"For to faile into the river of London coming from the northwards, you must come neere the coast to the northwards of Orfordnes, which is to the northwards of all the sands, there lye Aldbrough, Dunwich, Walderswike, Sowle and Covehit, all betwixt Orfordnes and Leystaff. Couehit is a sharp steeple like at also Leystaffe, but Sowle and Walderswyke , Aldbrough and Orfordnes are all flat steeples Sowle and Dunwich lye both upon the high land , betwixt them both is a valley, therein you may see Walderswike when you are thwart of it, Dunwich is the best to be knowne of all these foresaid places : it hath two flat steeples [our emphasis] and on both sides some trees….."* *"Betwixt Dunwich and Covehit lyeth the haven of Sowle which is a little shoulde river, a little within it divideth it itself into three parts, upon the northernmost arme lieth Sowle , upon the middlemost Walderswyke, and upon the southernmost Dunwich"*	**Admiralty Library**
1671	Seller	***The English Pilot***	Dunwich perspective shown	**Early English Books Online**
1671	Seller	***The Coasting pilot***	Same text as with other Seller Coasting pilots but a different perspective view again shows the cliff. Dunwich is not named	**Early English Books Online**
1673	Seller	***The Coasting Pilot***	Dunwich named on map but difficult to see any detail at coast. Dunwich perspective shown. Plus description as follows Chap II Page 3: *" From Aldborough alongst by Dunwich and Covehith.... The coast lieth North by East, somewhat Easterly, from Covehith to Leyslaff, North and South, two leagues. Between Dunwich and Covehith, lieth the Haven of Southwold, which is a small Creek, and a little within it divideth it self into three parts; upon the Northernmost, arm lieth Southwold, upon the Middlemost Walderswick, and upon thee Southermost, Dunwich".*	**Early English Books Online**
1675	Seller	***The coasting pilot*** *Published by John Seller, hydrographer to the King.* , [London : s.n., 1675]	A later edition same text, map and perspective as Seller 1673	Early English Books Online
1693	Collins	***Great Britain's Coasting-Pilot.*** **Printed by Freeman Collins and are to be sold by Richard Mount, 1693**	Chart Dover - Yarmouth showing river mouth and churches at Dunwich, Dunwich is on high ground	**Early English Books Online**
1708	Seller	**The English Pilot Part 2 and Part 1) Admiralty library**	A later edition same text, map and perspective as Seller 1673	Admiralty Library
1715	Seller	**The English Pilot**	A later edition same text, map and perspective as	Admiralty

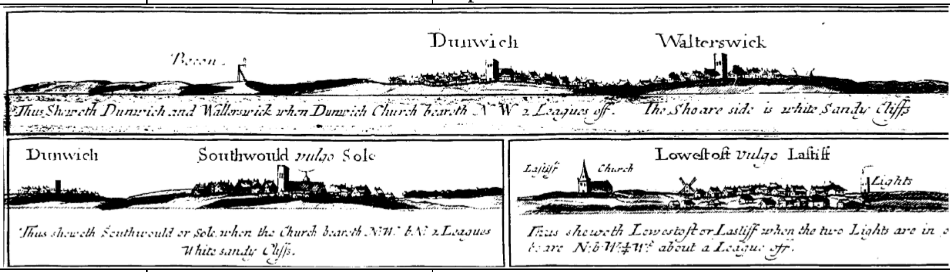
		Part 2 and Part 1) Admiralty library	Seller 1673	Library
?	Sayer	*Compleat Channel pilot*	*Map but not very detailed*	**UoS Library rare books**
1760	Master in the RN	*Channel Pilot and Sailing directions*	Stops at Orfordness	Historic Books JISC
1761	Du Bocage, Georges Boissaye	*Le petit Neptune françois*: or, the French coasting pilot. Being a particular description of the ... coast of France.	Terminates just north of Thames mouth	Historic Books JISC
1778	Chandler	*Coasting directions for the north and south channels of the river Thames: also directions from Lowestoff-Roads*	Map, shows Dunwich but not very detailed	Historic Books JISC
1781	**Greenville Collins**	***The Coasting Pilot***	*p 18 "Directions from Orfordness to Yarmouth - Halfway between Aldborough and Dunwich there is a wood in form of a saddle, which is a good mark to know the land, being the first discouvered when you fall in with this land, the shore lies from Orfordness to Lowestoffe N. by E. "* *"Dunwich, Walterswich and Sole, or Southwold, go all in one small creek, and divides into three branches. Dunwich on the South Branch, Sole, on the north and Walterswich in the middle. This is a bar haven, where at high water small vessels go in; there is good anchoring against these places from 8 to 12 fathoms"* *Map shows the harbour shrunk from the earlier version 1693 – but could be cartographic interpretation only.*	**UoS Library**
1788	Chandler	***The seaman's guide and new coaster's companion***. In two parts. Part I. Coasting directions from London through all the	Dunwich cliffs only mentioned	Historic Books JISC
1790	John Hamilton Moore	*The Coasting Companion*	Dunwich is not mentioned in the directions for going from Orfordness to Winterton Ness pp30-31 – However, South wold is mentioned.	UoS Library
1792	Chandler	as above	as above	Historic Books JISC
1795	Chandler	as above	as above	Historic Books JISC
1795	Stephenson, John	*The channel pilot, comprehending the harbours, bays, and roads in the British channel*	Stops just south of Dunwich	Historic Books JISC

1846	Norie, J.W	*New and extensive Sailing Directions for the navigation of the North Sea ... Seventh edition, ...*	*Dunwich church mentioned*	Historic Books JISC
1852	British and Foreign Coaster	*British and Foreign Coaster's Guide; containing complete sailing directions for the east coasts of England and Scotland, the*	Dunwich town mentioned briefly	Historic Books JISC
1854	Norie, J.W	*Sailing Directions for the East Coast of England, from London to ... Newcastle ... Likewise Part of the North Coast of France,*	Dunwich town mentioned briefly	Historic Books JISC
1869	James Imray and Son	*Sailing directions for the east coast of England, from Orfordness to the River Tyne, etc*	Just Dunwich bank and village mentioned briefly only	Historic Books JISC
1869	Hydrograhic office, Admiralty	*North Sea Pilot - Pt 3 East Coast of England 2nd Edition*	Same text as 1883 below	Historic Books JISC
1878	Hydrograhic office, Admiralty	*North Sea Pilot - Pt 3 East Coast of England 3rd Edition*	Does not appear to have Dunwich	Historic Books JISC
1883	Hydrograhic office, Admiralty	*North Sea Pilot - Pt 3 East Coast of England 4th Edition*	Mentions Dunwich and the ruins and history	Historic Books JISC
1897	Hydrograhic office, Admiralty	*North Sea Pilot - Pt 3 East Coast of England 6th Edition*	p258-259 same text as above	Historic Books JISC

Table A1.2: Extracts from sailing directions contained within various sea atlases.

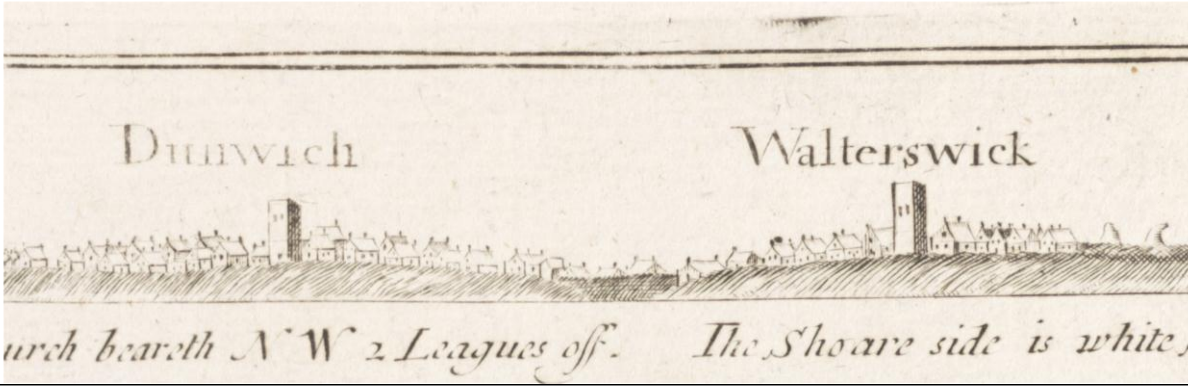
Date	Source	Description	Location
1637	**Columne - *The fierie sea-columne***	The perspective below shows **2 churches** with flat steeples (ie towers without spires), 2 windmills and the cliff at Dunwich.	Admiralty Library
			
1671	**Seller - *The English Pilot***	Dunwich perspective shows a single church, 2 windmills and other buildings and the cliff face. Possibility that the ruins of the church previously shown on the 1637 Columne view are to be seen to the right (north) of church tower.	Early English Books Online
			
1671	**Seller - *The coasting pilot:***	A different perspective view to the English pilot, again shows the cliff. Dunwich is named but the detail is hard to see on this digital copy	Early English Books Online
Thus sheweth the Land from Orfordness to Wintertonness.  *Thus sheweth the Coast of* England, *between* Orfordness *and* Sowl-Haven.			
1673	**Seller - *The coasting pilot***	Dunwich perspective shows the town on high ground with a prominent church. Southwold Harbour is shown as a 2-armed creek. The Dunwich river is not shown presumably due to the fact that it is hidden from the artists view.	Early English Books Online
 Thus sheweth the Land from *Dunwich* to *Southwold*.			

1675	Seller - ***The coasting pilot***		A later edition same perspective as Seller 1673	Early English Books Online
1693	**Collins - *Great Britain's coasting-pilot.***		Much more detailed view of Dunwich with a single church shown but giving an apparently more detailed impression of the town. This online version is not very high resolution. See later version professionally reproduced for this project. In fact this is simply a representation.	Early English Books Online

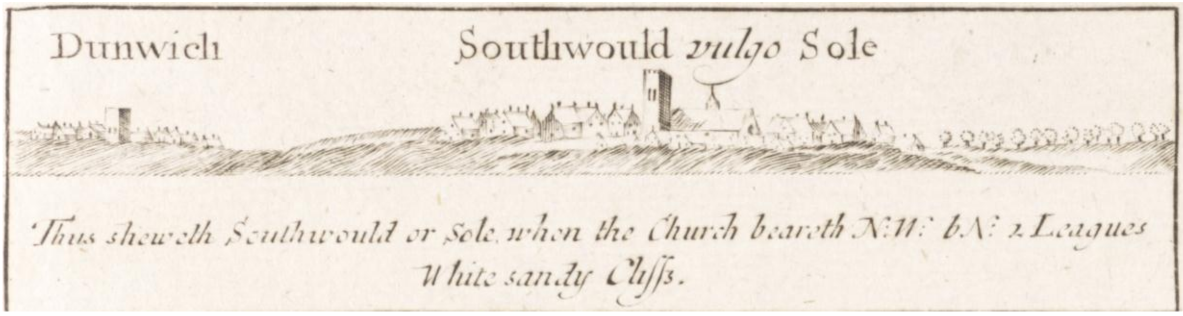


1708	Seller **<u>- The English Pilot Part 2 and Part 1)</u>**		A later edition same text, map and perspective as Seller 1673	Admiralty Library
1715	Seller**<u>- The English Pilot Part 2 and Part 1)</u>**		A later edition same text, map and perspective as Seller 1673	Admiralty Library
1745	**Collins - *The Coasting pilot***		Detailed perspective of the Extent of the town and a prominent church – as below.	Admiralty Library
1781	**Collins - *The Coasting pilot***		Perspective showing the town of Dunwich and a single prominent church. This offers the most detailed representation of the town within the sea atlases. However, it appears to be indicative only since there is no evidence of the settlements being almost joined. There are 2 perspectives showing Dunwich, one Dunwich to Walberswick, the other Dunwich and Southwold.	**UoS Library**

Dunwich and Walberswick

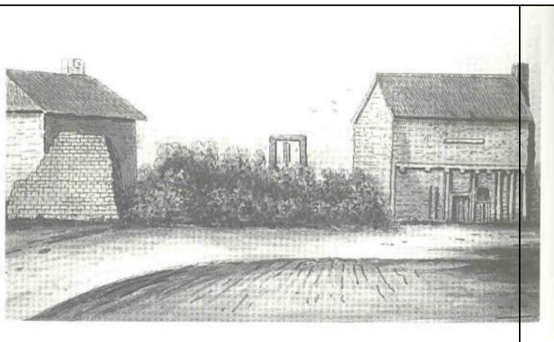
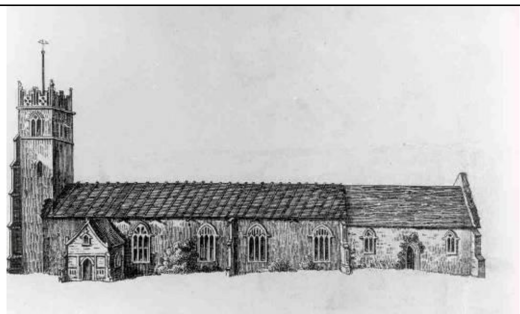
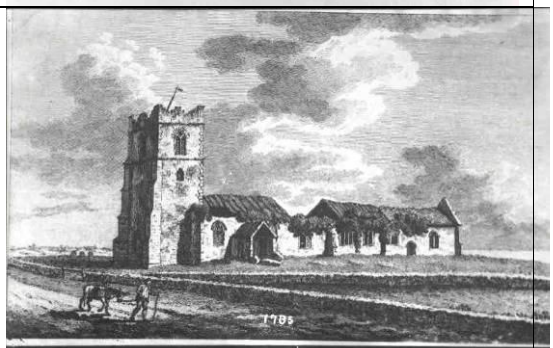
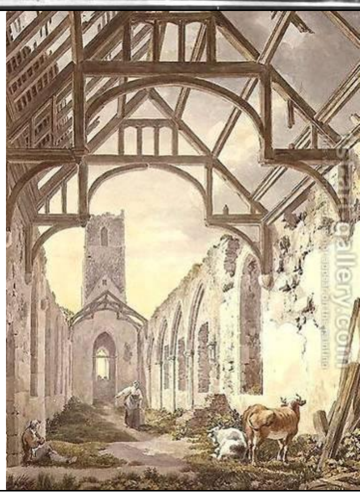


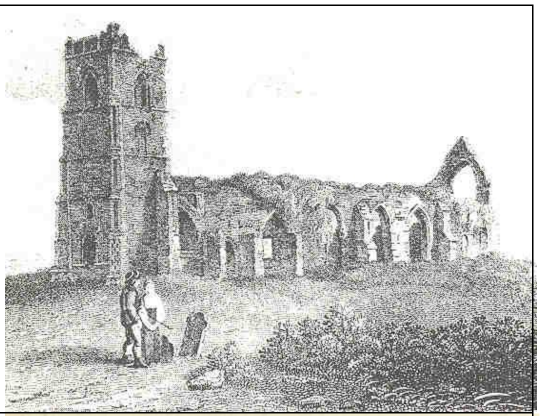
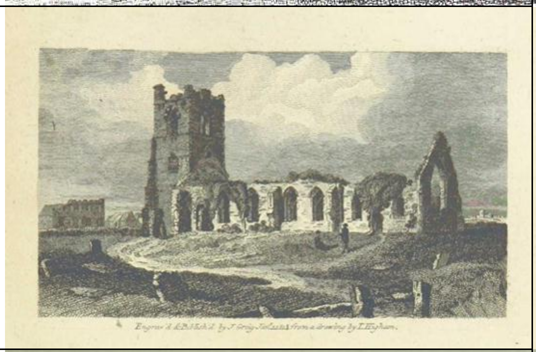
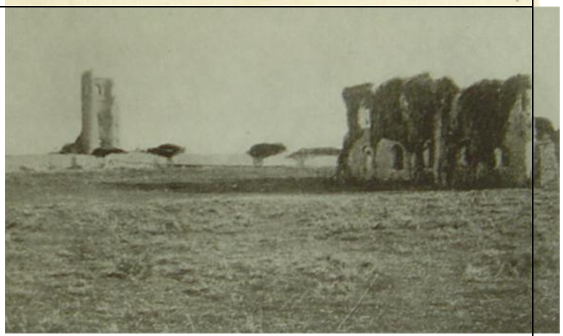
Dunwich and Walberswick (enlarged)

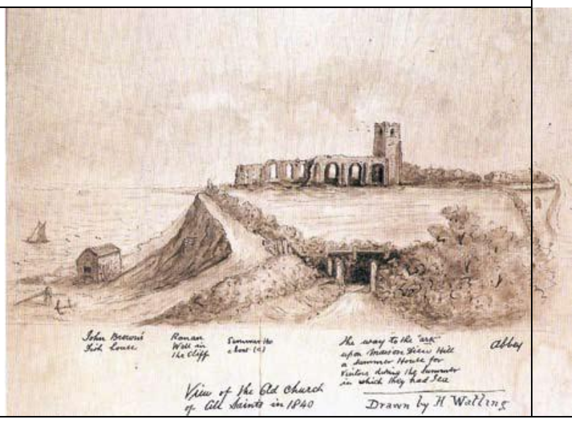


Dunwich and Southwold

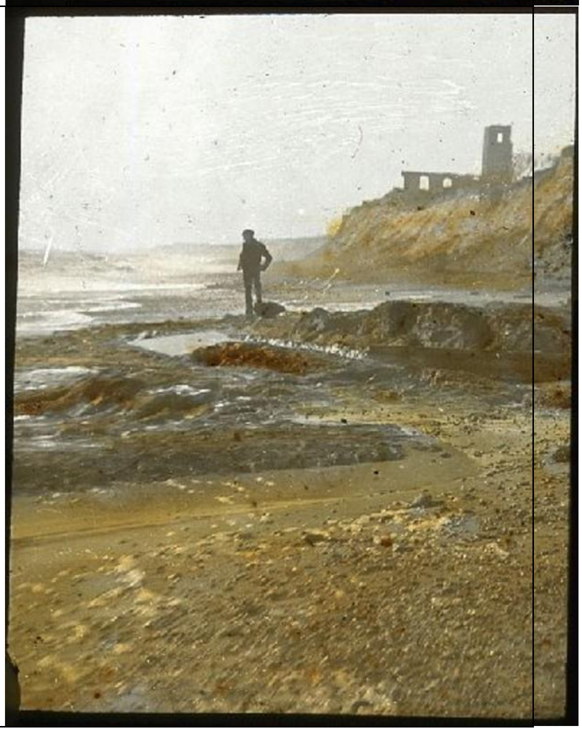
Table A1.3: Coastal perspective sketches contained within various sea atlases

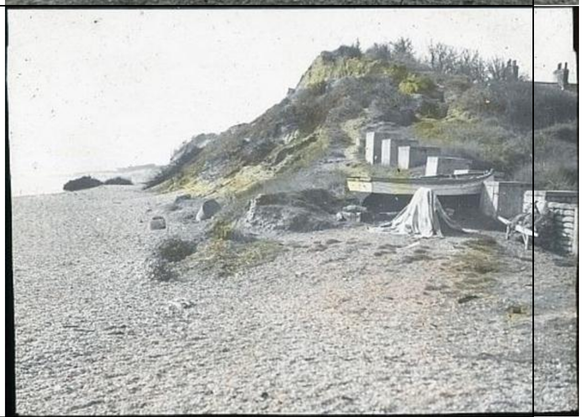
Name	Author	Date	Description	Thumbnail
Images of specific Buildings				
Maison Dieu (Dunwich Museum)	***Hamlet Watling copy of Nathaniel Back (Bacon?)***	c.1690	Redrawing of a sketch by Nathaniel Back showing the buildings associated with the Maison Dieu, including remains of a stone wall, and the Maison Dieu house. Maison Dieu lane shown curving right towards the sea – probable location of view now the entrance to the beach car park . 2011 Time Team dig confirmed buildings lie under current Café/Toilets	
All Saints Church, Dunwich	***Joshua Kirby***	1753	All Saints Church a south view. Details of the flushwork in the top of the tower and the leaded roof of the nave. Windows are early English design.	
All Saints Church, Dunwich	Samuel Hooper London	1772	Good view from couth of the Church of All Saints, showing collapse of the roof. Detail of the road between the churchyard and the perimeter wall of Greyfriars	
Dunwich Church	***Michael Angelo Rooker***	c.1790	Ruins of All Saints Church, showing details of the hammer beam roof, and single narrow nave. Bays of the north aisle are blocked in. Illustrates the sequence of decay followed by Dunwich churches once closed and abandoned.	

All Saints Church, Dunwich		c.1800	All Saints church now roofless and all windows gone. Limited topographic information.	
All Saints Church, Dunwich	*I. Higham*	c. 1840	All Saints Church from the south east showing the edge of the cliff and fencing in the foreground. Relationship to Greyfriars "The Place" house of Downings/Barnes shown in the background.	
View of Greyfriars with the Tower of All Saints	*Morley*	1898	Shows the relationship between the existing remains of Greyfriars friary and All Saints, with the perimeter wall separating the two. Land rises up towards All Saints, confirming the topography shown in earlier drawings..	
Topographic Images				
Dunwich, Suffolk (National Gallery)	***J.M.W. Turner***	1830	Artistic interpretation of Dunwich in which the ruins of All Saints have been rotated 180 degrees to place the tower on the cliffs. Additional ruins added, and the scale of the cliffs has been accentuated. Value is limited.	

Dunwich, Gardner (1754) (Dunwich Museum)	***Joshua Kirby***	1753	General view of Dunwich from the shingle bank to the north. Key features include the back barrier marsh and wetland and the line of St James Street with buildings just above the level of he marsh. The picture also shows the topography of the land which rises from the Dunwich river (far right) to the highest point occupied by All Saints church. This high land sloeps steeply down to the shingle bank and marsh to the north. Greyfriars ("The Place" house of the Downing Estate) is on slightly lower land west of All Saints. The land slopes gently seaward, with cliff heights being slightly lower than present. A narrow beach is evident at the foot of the cliffs with boats drawn up to the beach.	
View of the old church of All Saints in 1840. (Dunwich Museum)	*Hamlet Watling*	1840	Topographic details of the land north of All Saints, showing a road east of the boundary line, and a dip before rising up on to Maison Dieu hill (foreground). Cliffs show accumulation at the toe ,and Fishermans hut on beach.	
Details of the Beach and Cliff				
Beach at Dunwich (Private)	*Thomas Smythe (1825-1906)*	c. 1860	This view is important because it shows the only known visual evidence of extensive sea defences and a groyne to protect the cliffs at Dunwich. Beach is low relief,	

			suggesting less sediment (and need for defences at toe of cliffs).	
Dunwich, Suffolk (Private)	*John Mogford*	1877	View of cliffs and beach with All Saints Church set back from the edge. Beach is clearly well developed and slopes up to the toe of the cliffs much as it does today. Gap in cliffs at end of Maison Dieu lane with evidence of higher land north of it where now it is a shingle bank. Note boats drawn up on beach as shown in Agas 1587 map.	
Minsmere Cliff'	*Walter Daniel Batley*	1897	A detailed view of the cliff and beach just south of Dunwich. All Saints church tower is just visible. The state of the cliffs shows it to be active, with accumulation at the toe. The beach is sandy and slopes towards the sea – suggesting similar conditions to today.	
Dunwich Mount, Suffolk (Dunwich Museum)	*Edward J. Lingwood*	1911	Remains of a "tumulus", lost to the sea during storms in the early 20th century. This was excavated and found to overly the Pales Dyke and is thus not a tumulus as such but most likely an artificial mound built as a look out tower for the fishing industry.	

All saints Church, Dunwich	*Dowcra collection*	1904	Cliffs looking south showing evidence for a beach and an active cliff face. Accumulation of material at toe of cliff.	
Dunwich after 1911 storm. Dunwich Museum.	*Fisk collection*	1911	Dunwich during the 1911 storm, showing evidence of erosion of the cliff face, and removal of the beach. Note height of waves relative to cliff line, indicating removal of beach during the storm and high water levels.	
Dunwich Museum	*Fisk Collection*	1911	Foundation of buildings exposed on the beach following the storm of 30/09/1911-01/10/1911. the storm removed beach material down to former building foundations and exposed the toe of cliffs.	

Dunwich Museum	*Fisk Collection*	1913	Dunwich looking south along the beach towards All Saints church. Faggots in the foreground are to protect the shallow cliff face exposed by the storm of 1911. Beach is present.	
Dunwich Museum	*Fisk Collection*	1914	Beach clearly present, and cliffs showing recent collapsed material beginning to accumulate at toe of the cliff.	
Dunwich Museum	*Fisk Collection*	1949	Almost the same view as above. Note low cliff line is still exposed but beach now higher and covering cliff line in foreground. Cliff face now has a more gentle angle due to accumulated material at the toe.	
Dunwich Museum	*Fisk Collection*	1908	View from Maison Dieu hill looking north showing fishing huts and shingle bank at high tide. Morphology of this bank appears wider than the managed barrier of recent years. Gravel/sand drapes extend over the marsh – probably from 1911 storm. Shingle barrier migrates landwards over the surface of the marshes, revealing peat at the toe of the beach. Cliff line retreat is likely to control migration rate.	

Dunwich Museum	*Fisk Collection*	1949	View from Maison Dieu hill looking north showing the line of tank traps, pill box and shingle bank.	

Table A1.4: Examples of the information contained in artistic and photographic representations of Dunwich.

APPENDIX 2:0 Wessex Archaeology Magnetometer report

APPENDIX 3.0: DIDSON Data

Date / Survey	DIDSON Files	Site	Description
June 24th 2010 BBC One Show. Divers: Dan Snow / Andy Rose	2010_06-24_110217_LF.ddf 2010_06-24_110226_LF.ddf 2010_06-24_110229_HF.ddf 2010_06-24_110235_HF.ddf 2010_06-24_110240_HF.ddf 2010_06-24_110318_HF.ddf 2010_06-24_110325_HF.ddf 2010_06-24_110332_HF.ddf 2010_06-24_110333_HF.ddf 2010_06-24_110335_HF.ddf	St Katherine Chapel	A series of DIDSON diver held files taken around the St Katherines chapel site. Shows rubble and sand ripples on seafloor
June 24th 2010 BBC One Show. Divers: Dan Snow/Andy Rose	2010_06-24_165532_HF.ddf 2010_06-24_165535_HF.ddf 2010_06-24_165539_HF.ddf 2010_06-24_165541_HF.ddf 2010_06-24_165545_HF.ddf 2010_06-24_165549_HF.ddf 2010_06-24_165553_HF.ddf 2010_06-24_165557_HF.ddf 2010_06-24_165601_HF.ddf 2010_06-24_165603_HF.ddf 2010_06-24_165607_HF.ddf 2010_06-24_165611_HF.ddf 2010_06-24_165615_HF.ddf 2010_06-24_165619_HF.ddf 2010_06-24_165622_HF.ddf	St Nicholas Church	A series of DIDSON diver held files taken around the St Nicholas church site. Shows large stones and square blocks of masonary.
July 7th 2010 BBC Oceans Divers: Frank Pope/Andy Rose	2010_07-19_130454_HF.ddf 2010_07-19_130500_HF.ddf 2010_07-19_130538_HF.ddf 2010_07-19_130543_HF.ddf 2010_07-19_130545_HF.ddf 2010_07-19_130551_HF.ddf 2010_07-19_130553_HF.ddf 2010_07-19_130558_HF.ddf 2010_07-19_130604_HF.ddf 2010_07-19_130609_HF.ddf 2010_07-19_130614_HF.ddf 2010_07-19_130619_HF.ddf 2010_07-19_130626_HF.ddf 2010_07-19_130632_HF.ddf 2010_07-19_130638_HF.ddf	Blackfriars Friary	A series of DIDSON diver held files taken around the Blackfriars Friary site. Shows stones and some larger blocks of masonary. Sand ripples and possible bedrock
July 7th 2010 BBC Oceans Divers: Frank Pope/Andy Rose	2010_07-19_114447_HF.ddf 2010_07-19_114450_HF.ddf 2010_07-19_114457_HF.ddf 2010_07-19_114504_HF.ddf 2010_07-19_114512_HF.ddf 2010_07-19_114520_HF.ddf 2010_07-19_114526_HF.ddf 2010_07-19_114531_HF.ddf	St Peter's Church	A series of DIDSON diver held files taken around the St Peter's church site. Shows large stones and square blocks of masonary. Sand ripples.

	2010_07-19_114537_HF.ddf 2010_07-19_114543_HF.ddf 2010_07-19_114544_HF.ddf		
March 2012 EH Diver: Andy Rose	2012-04-03_182741_HF.ddf 2012-04-03_182800_HF.ddf 2012-04-03_182819_HF.ddf 2012-04-03_182840_HF.ddf 2012-04-03_182902_HF.ddf 2012-04-03_182906_HF.ddf 2012-04-03_182926_HF.ddf 2012-04-03_182938_HF.ddf 2012-04-03_182942_HF.ddf 2012-04-03_182949_HF.ddf 2012-04-03_182953_HF.ddf	St Katherine Chapel	180-360 degree sweeps made from four points within ruins. Data mosaiced into site maps.

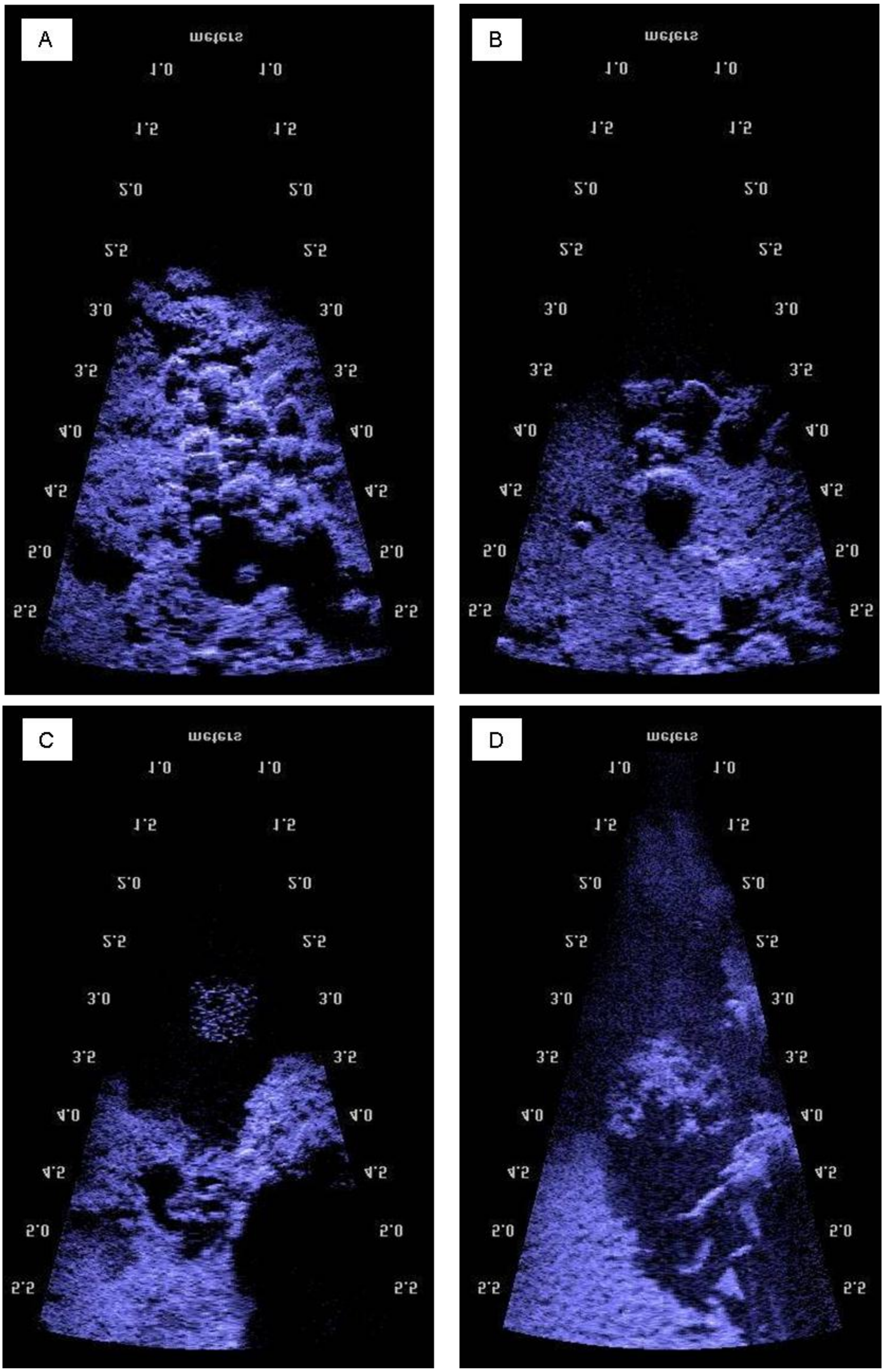
Table A3.1: DIDSON-DH files and dates of survey available for the Dunwich site.

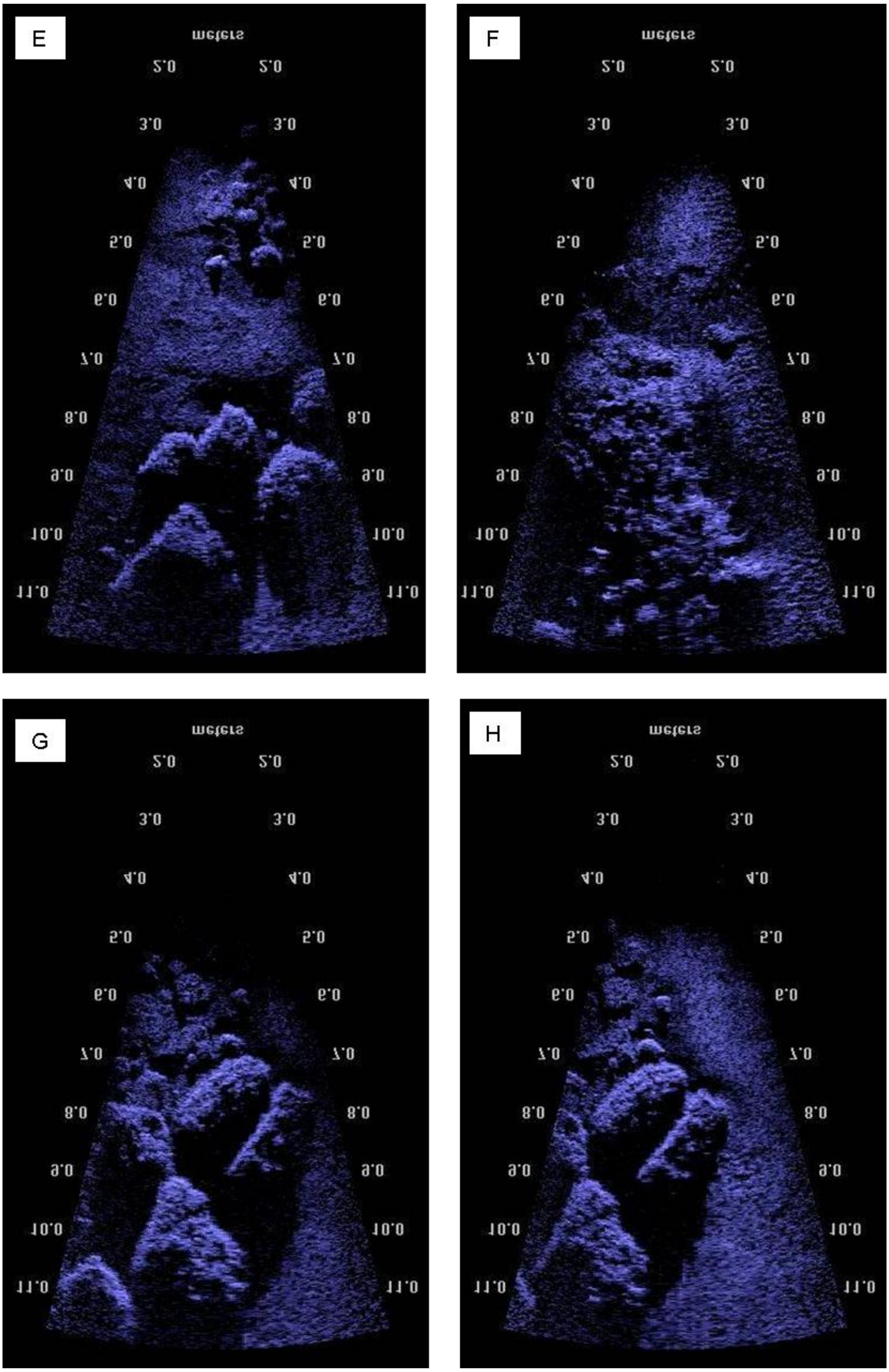
Figure(s)	Description
	St Peter's Church Site
A3.1A & B	Field of boulders and cobbles (<0.3m) with edges softened by marine growth. Sandy sediments in between.
A3.1C	Large block (c. 1.2m) with uneven surface and marine life. Shoal of small (<0.1m) fish in centre of image.
A3.1D	Rippled sand bed with large blocks with uneven surfaces of cobbles and boulders. Diver visible in bottom right.
A3.1E	Group of four large (1.3m) squared blocks with flat faces and uneven surfaces lying close together. Field of smaller blocks/boulders in foreground. Uneven sandy rippled seabed.
A3.1F	Scatter of boulders cobbles and smaller stones lying on an uneven sandy rippled seabed.
A3.1G & H	Filmed from south looking north. Group of 5 large (1.2-2.0m) blocks with uneven surfaces, flat sides and squared off corners. Smaller (<0.7m) block field in foreground. All surrounded by rippled sandy bed. Evidence of scour pits around blocks on western side.
	St Nicholas Church Site
A3.2A & B	Large blocks (1.0-1.4m) with flat sides, some with squared corners. Smaller boulder and blocks scattered around in between. Surface of blocks uneven with evidence of cobbles and boulders and marine life.
A3.2C & D	Large blocks (>1.0m) with flat faces and some squared corners lying among smaller (<0.5m) blocks and boulders. Sea bed appears pock-marked – perhaps stones?
A3.2E,F,G,H	Groups of smaller blocks, some with squared corners and flat faces lying on a bed with shallow depressions (E&F). In 2G & H seabed appears smoother – sand?
A3.2I,J,K	Seabed shows pock-marking and possible outcropping of bedrock (Crag?). Smaller (<0.5m) boulders and blocks can be seen but possibly fragmented bedrock?
A3.2L	Large block (1.3m) with uneven surface (stones) and flat sides

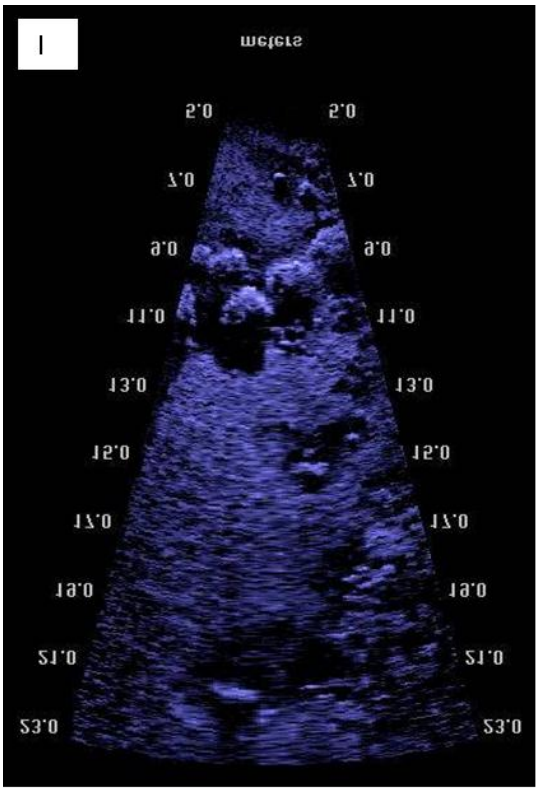
	with some squared corners. Its shadow obscures most of the image.
Blackfriars Site	
A3.3A & B	Partly buried irregular blocks with scour pits in a sandy rippled seabed. Possibility of a geological origin.
St Katherine's Chapel Site	
A3.4A	Square faced oblong block 1.75m x 0.5m resting against mortar rubble block. Uneven surface of the latter due to stones and marine life.
A3.4B	Large (1.6 – 1.3m) flat faced mortar and rubble block with rough surface composed of cobbles. Marine life visible on surface.
A3.4C	Area of stones, cobbles and boulders (0.3m) – marine life on surfaces clearly visible.
A3.4D	Area of Rubble blocks, boulders and cobbles on the margin of the site with a sandy rippled bed running off into the distance.
A3.4E	Isolated 1.3 x 0.8m block lying in a scour pit and partly buried by rippled sand. A cluster of smaller blocks closer to diver shows flat sides.
A3.4F	Same view as 4E though offset to right. Large blocks in foreground casting long shadows over image.
A3.4G	Diver filming NNE. Three large rubble/mortar blocks with rough surfaces showing stones within the mortar matrix and covering of marine life. Flat sides and squared corners. Large boulders and blocks (<0.5m) surround furthest block. Scour pits around blocks visible in a sandy rippled surface.
A3.4H & I	Diver filming SSW. Field of large (c.1.0m) blocks covering 7-19m range. Large block in foreground is perhaps the one shown in 4E.
A3.4J & K	Diver filming SSE. Field of blocks surrounded by sand. Some rippling evident in foreground but not further away due to reduced resolution.

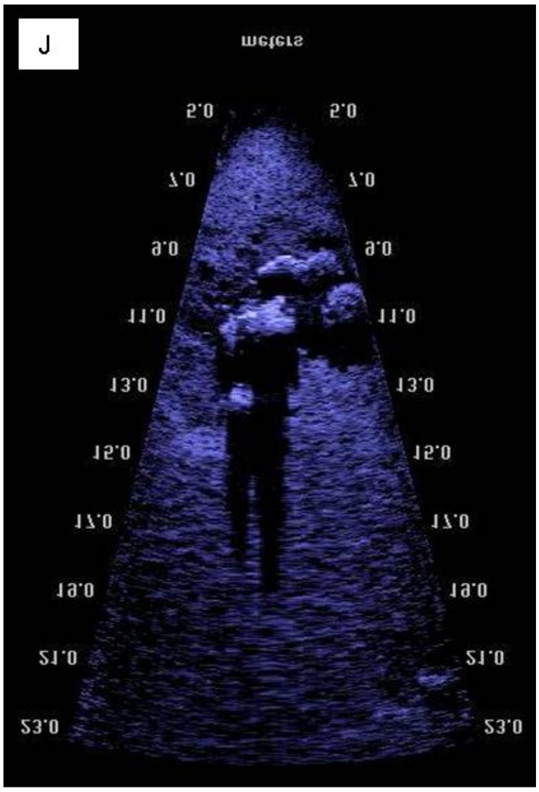
Table A3.2: DIDSON figure captions.

Figure A3.1:A-K St Peters Church Site BBC One Show June 2010




E
F
G
H


I


J

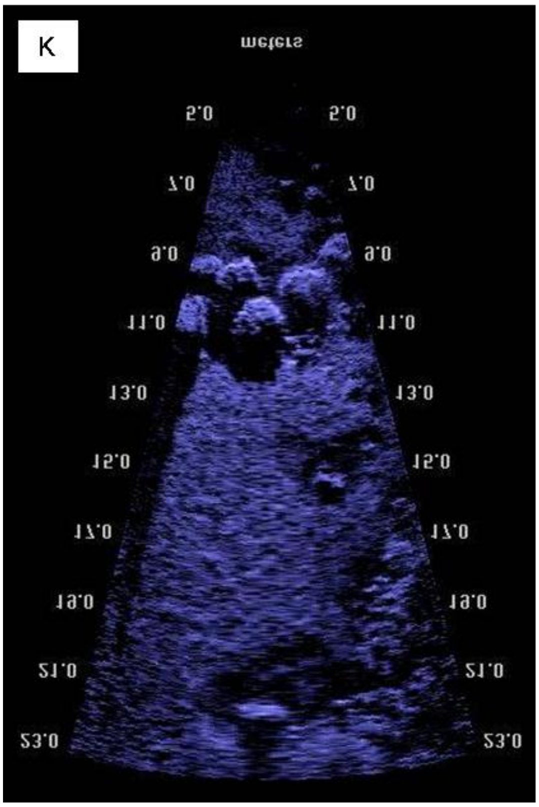
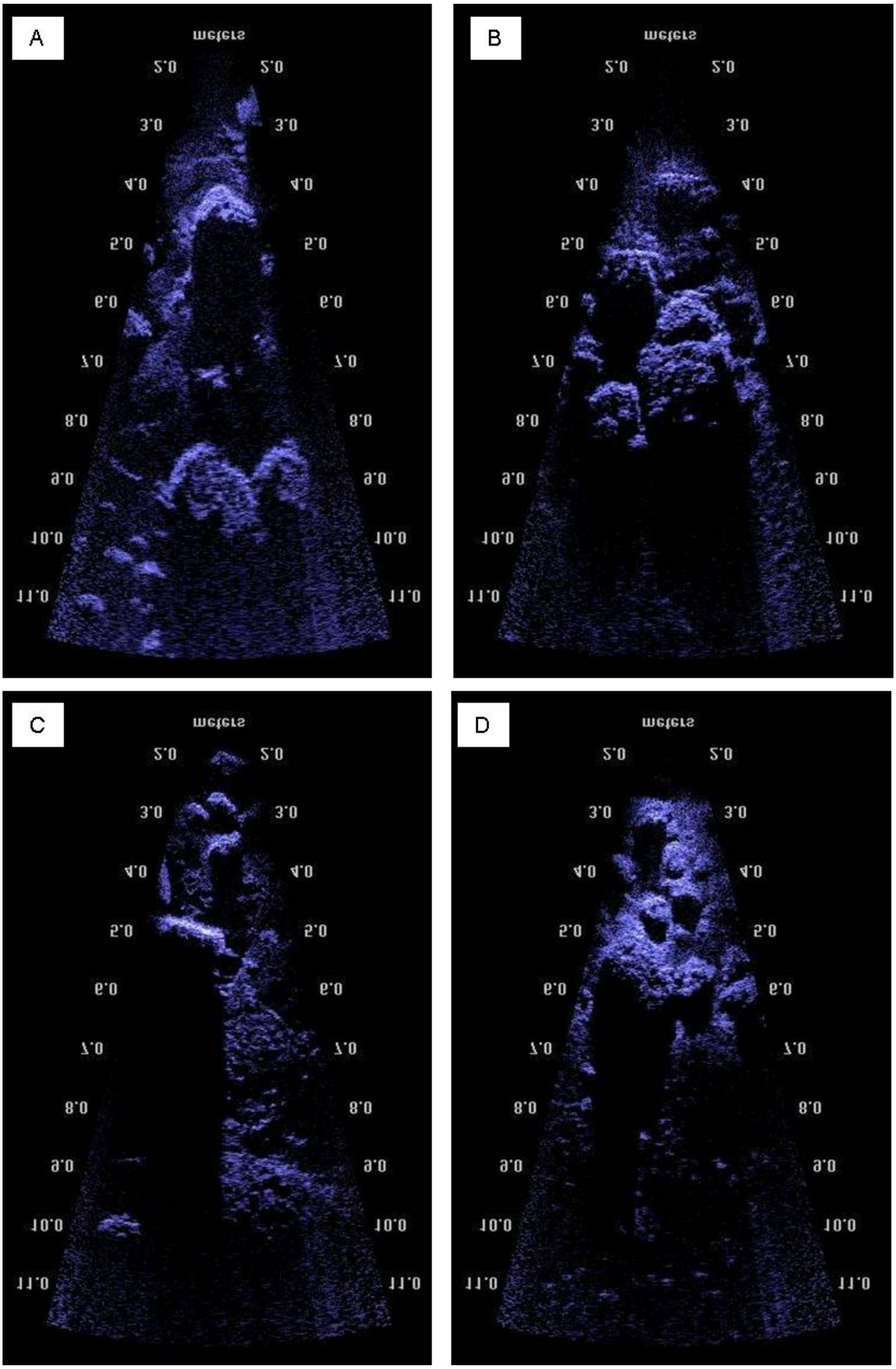
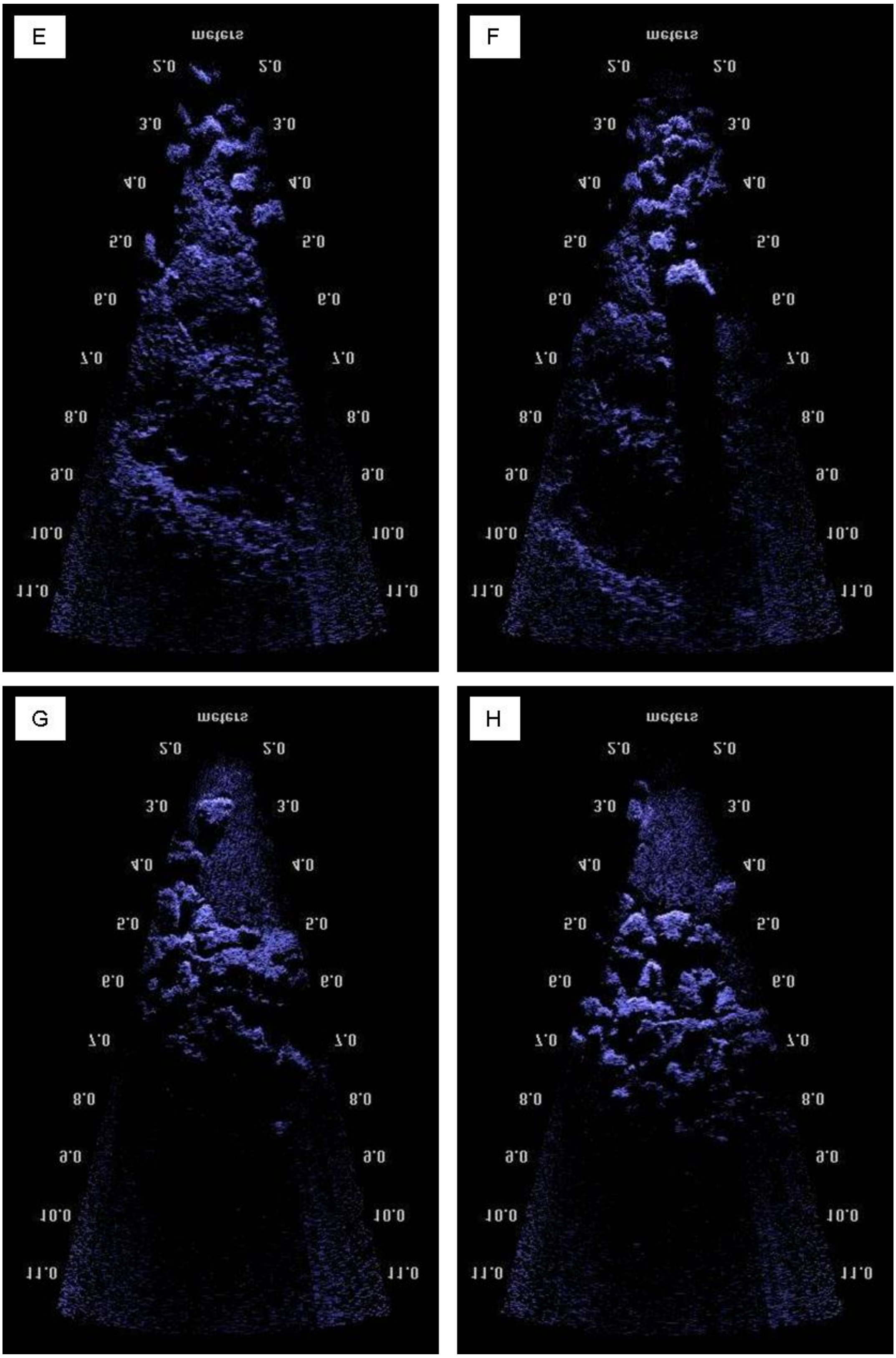

K

Figure A3.2:A – L St Nicholas Church Site BBC One Show June 2010




E
F
G
H

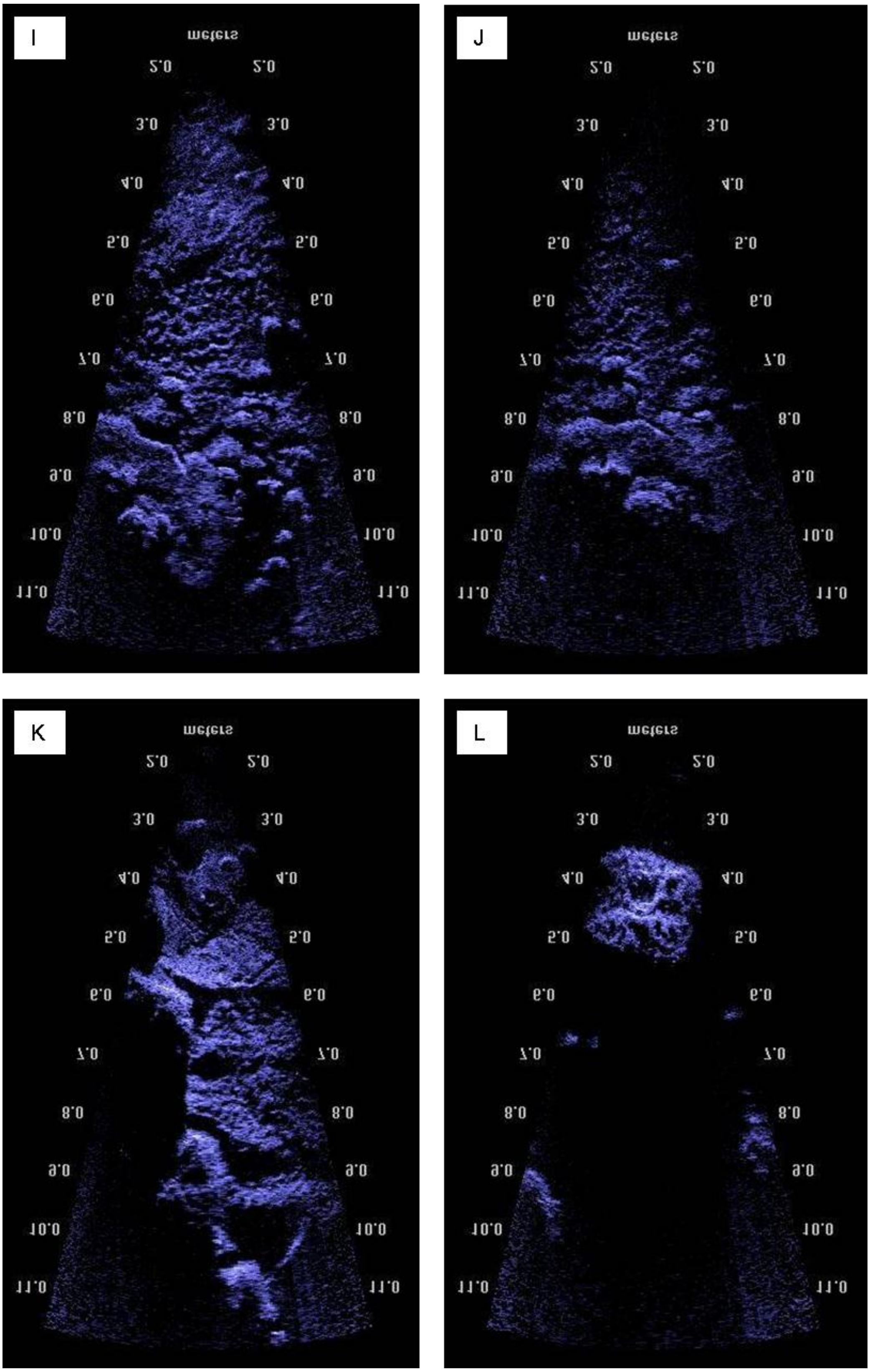

I
J
K
L

Figure A3.3A – B Blackfriars Site BBC Oceans July 2010

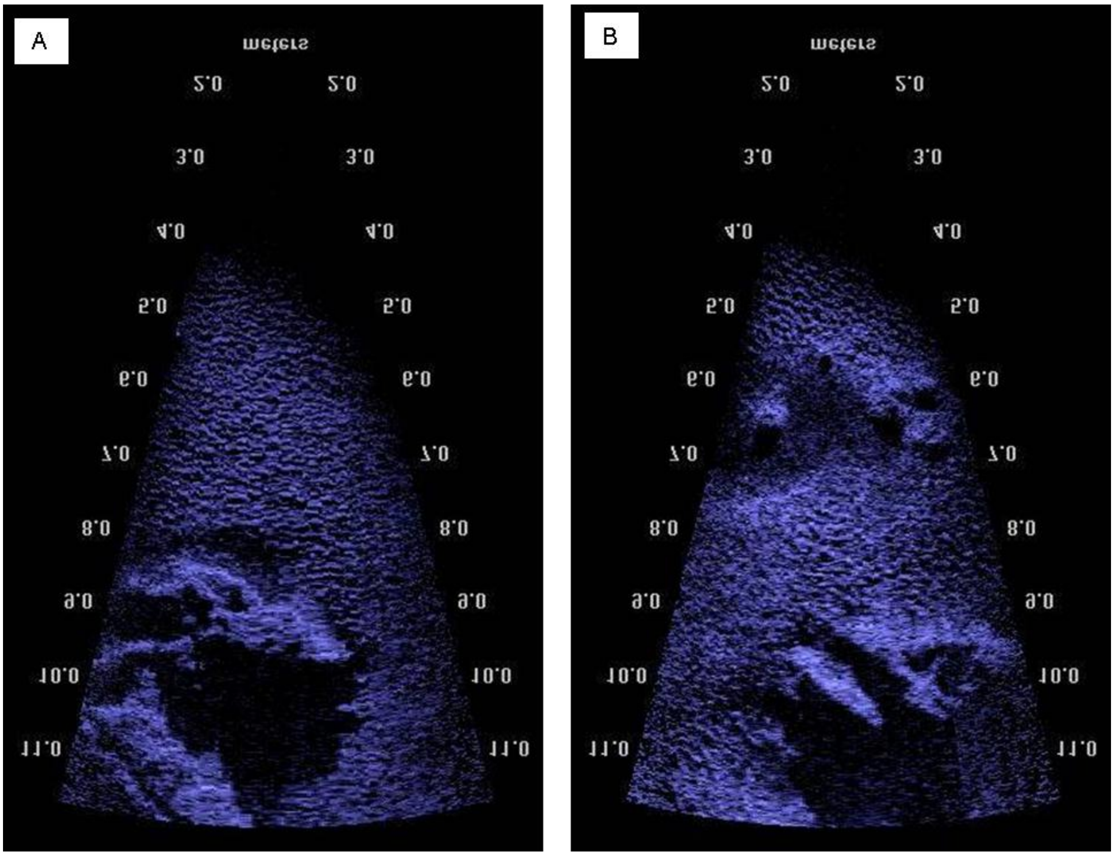
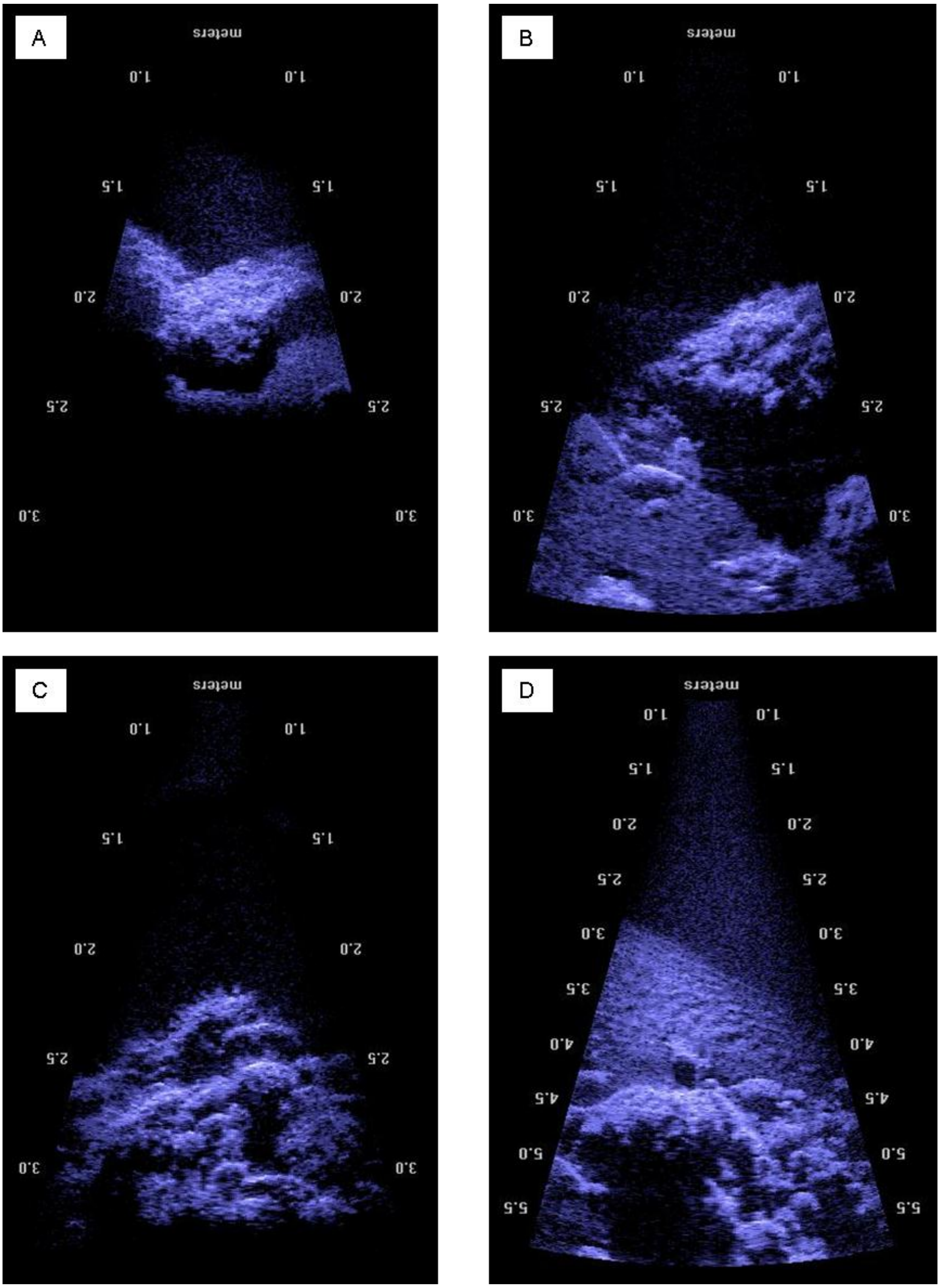
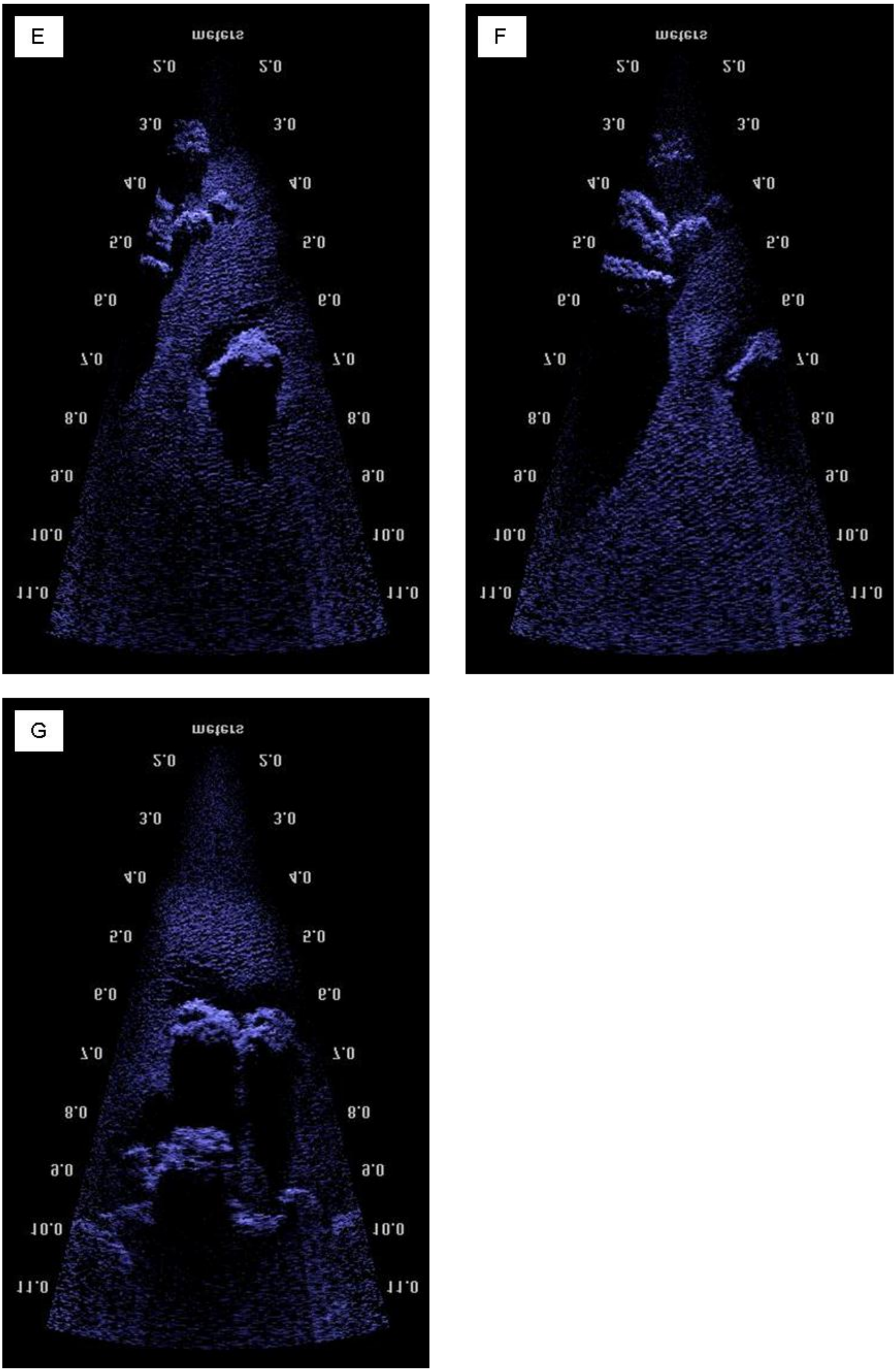
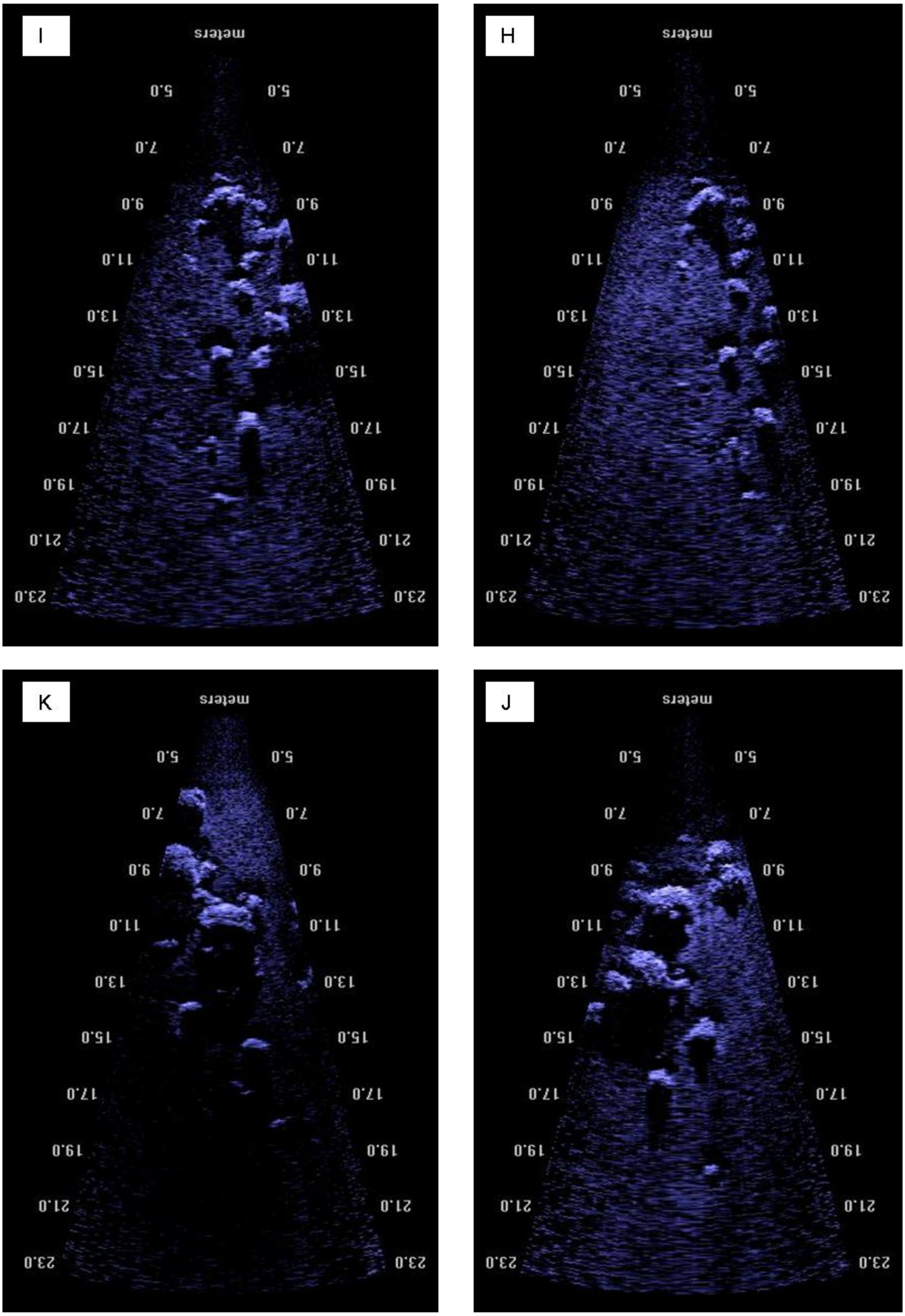


Figure A3.4:A – B St Katherine's Chapel Site 2012 Survey




E
F
G


I
H
K
J

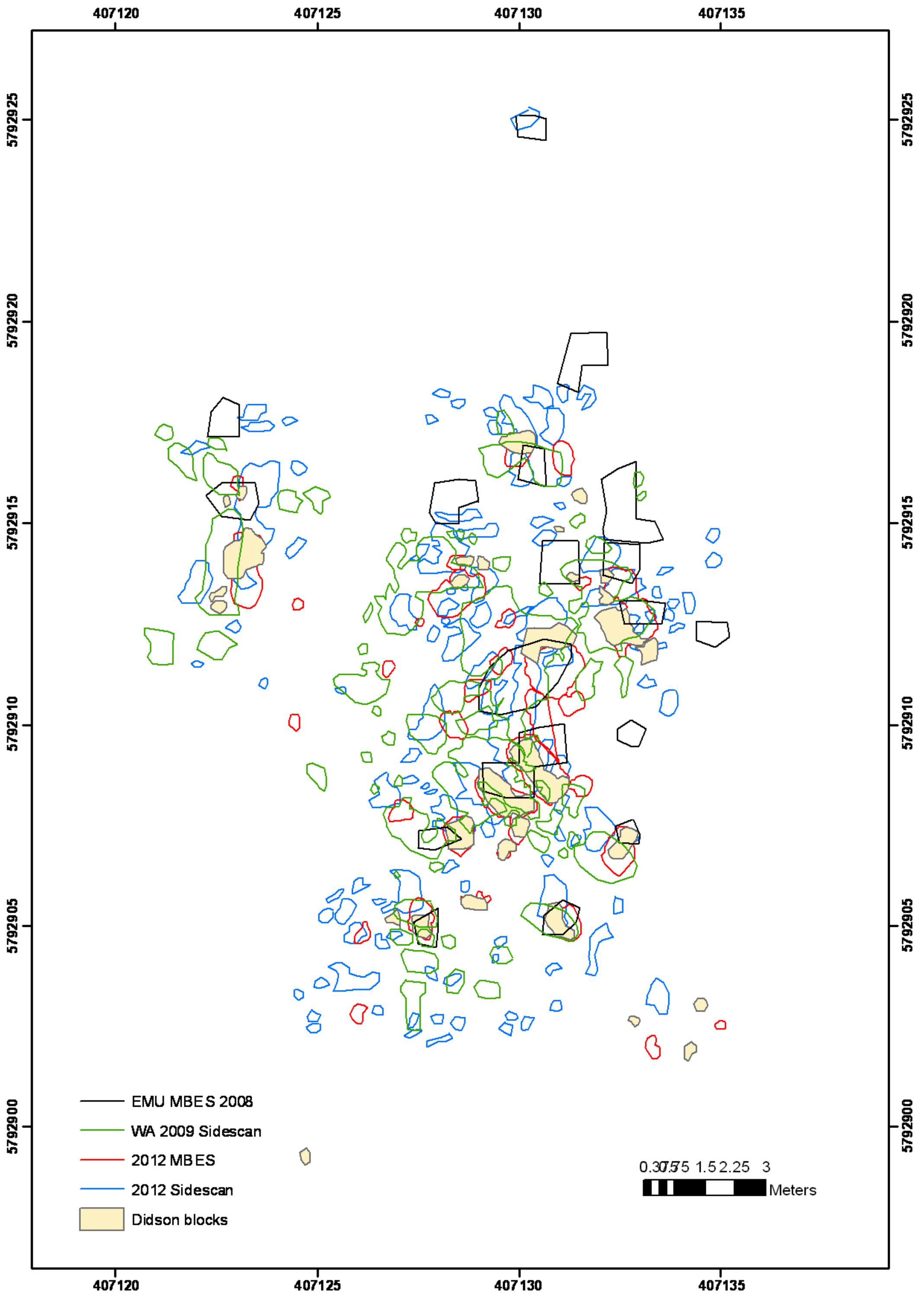


Figure A3.5: Geospatial overlay of block outlines digitised from the different geophysical surveys. Variation in number and size reflect a) accumulation of sand around the site, b) different resolution of the data capture and c) loss of data due to acoustic shadowing.

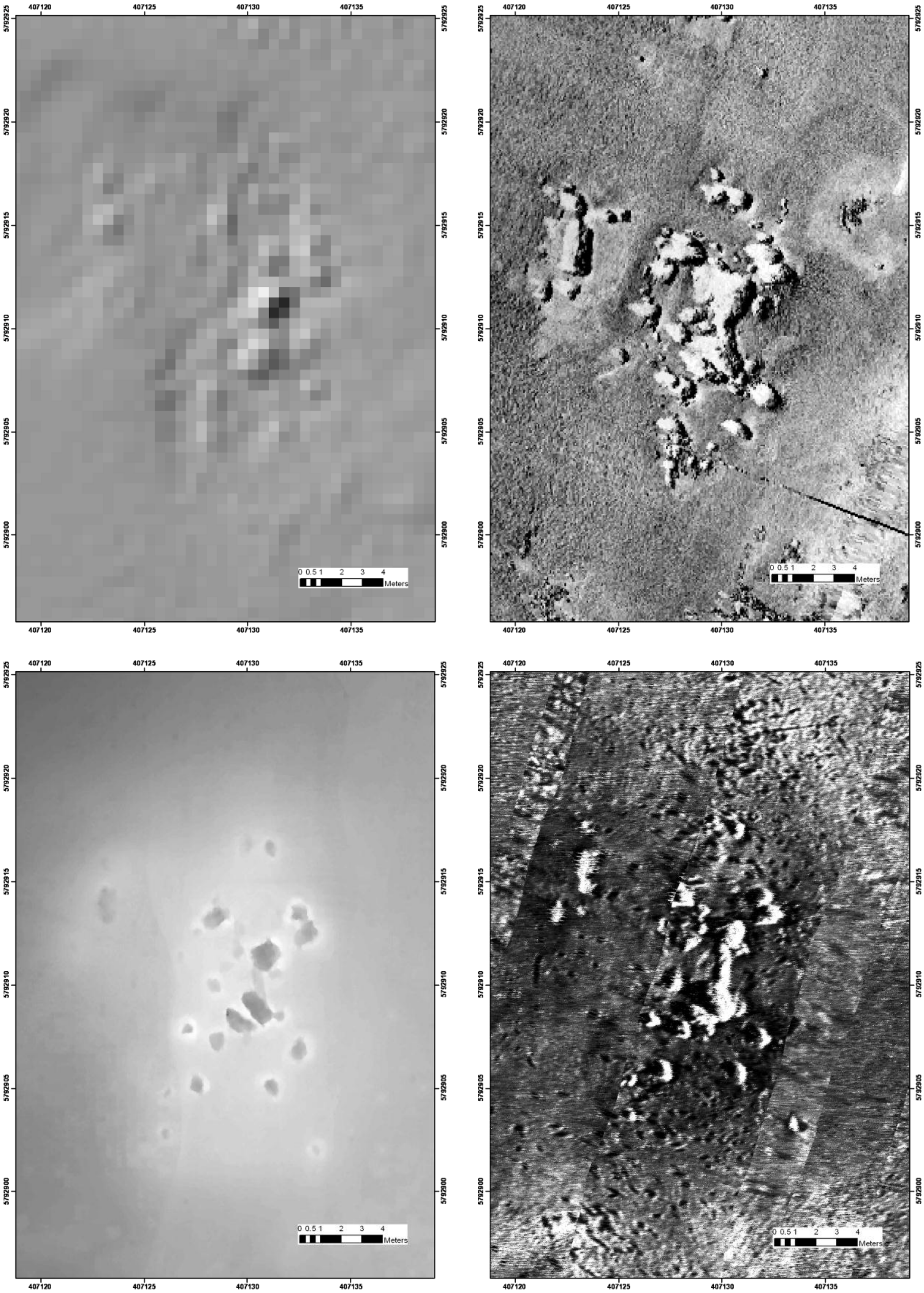


Figure A3.6: St Katherine's chapel site imaged using four different geophysical technologies. Top left MBES 2008, Top right SSS 2009, Bottom left MBES 2012, Bottom right SSS 2012.

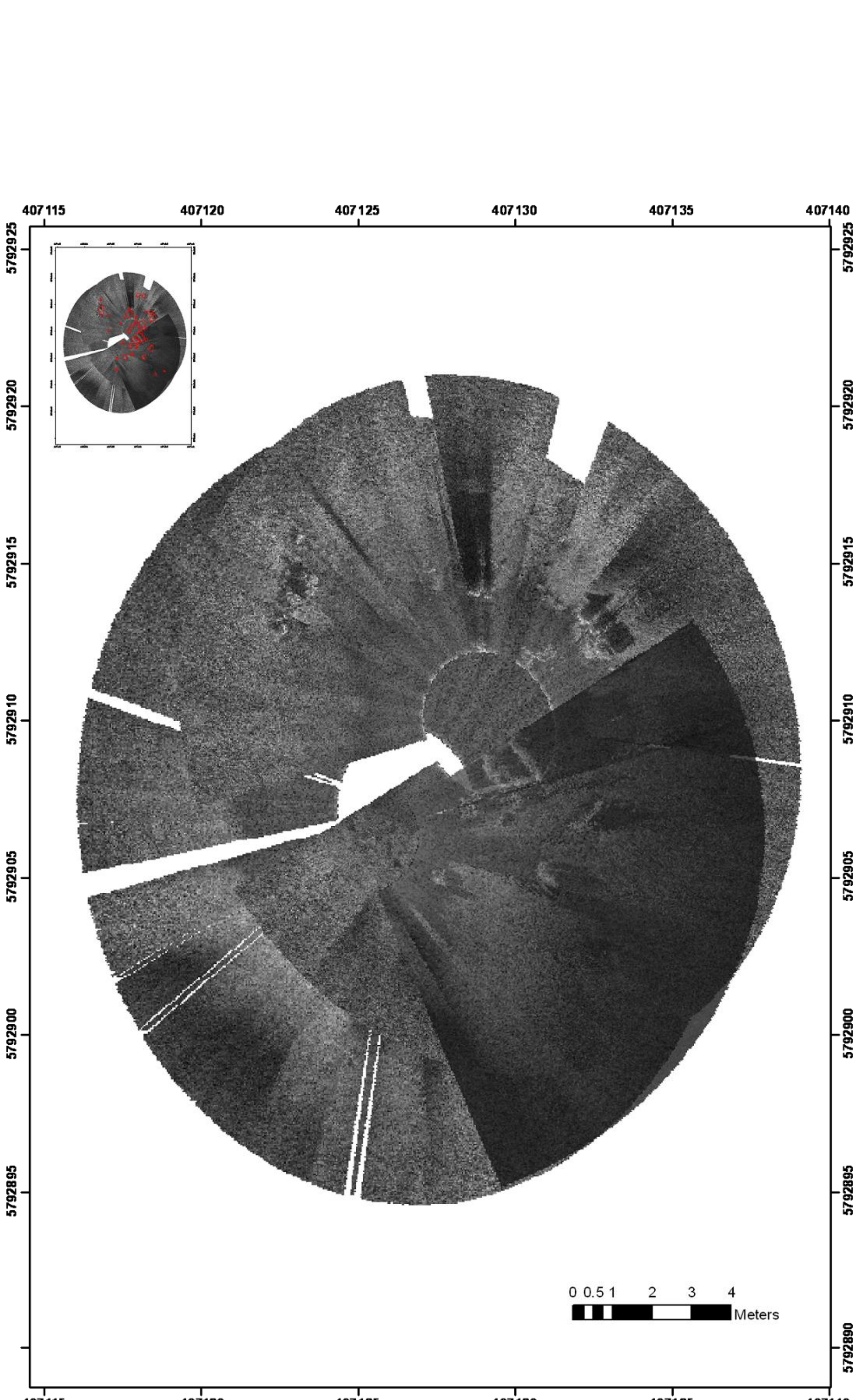


Figure A3.7: DIDSON mosaic of St Katherine's Chapel site.

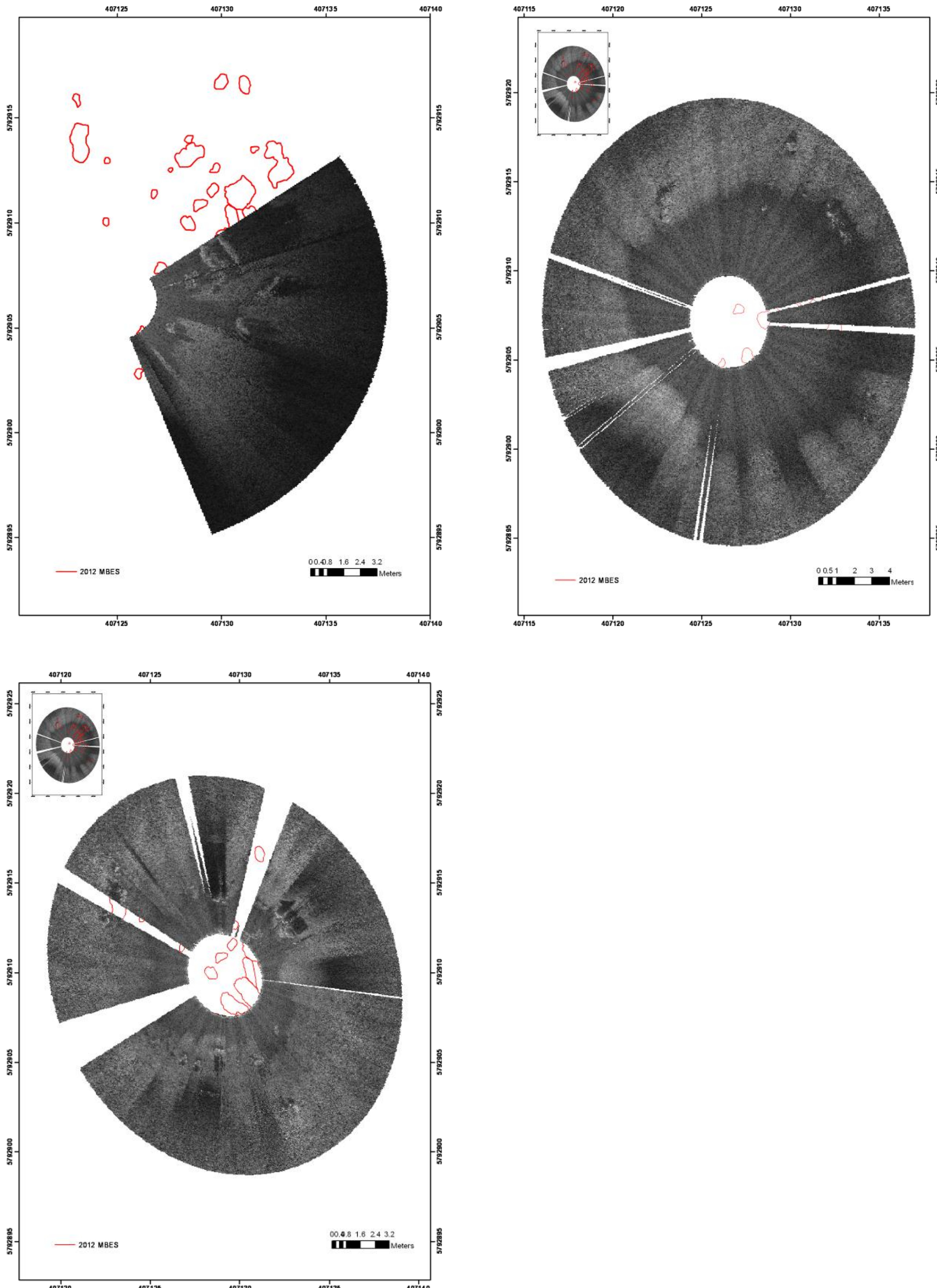


Figure A3.8: Individual DIDSON mosaics of St Katherine's Chapel site used to compile Figure A3.7.