UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL AND HUMAN SCIENCES

Department of Geography and Environment

Developing Terrestrial Laser Scanning of Threatened Coastal Archaeology with Special Reference to Intertidal Structures

by

Michael Alister Lobb

Thesis for the degree of Doctor of Philosophy

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DEVELOPING TERRESTRIAL LASER SCANNING OF THREATENED COASTAL ARCHAEOLOGY WITH SPECIAL REFERENCE TO INTERTIDAL STRUCTURES

Michael Alister Lobb

The aim of this thesis is to develop a means of using terrestrial laser scanning to rapidly record coastal and intertidal archaeology within its immediate environs and to use that context to understand its construction and function. Key to this is the underlying concept that structures built to exploit and utilise the resources of the intertidal zone are fully dependant on the dynamics of their immediate landscape. Terrestrial laser scanning provides a level of data not previously gathered in the recording of intertidal sites, allowing a highly detailed recording of complex three dimensional structures to a high level of accuracy, and, through integration with other forms of metric survey, the placement of this information within a wider topographic landscape.

The challenges of the intertidal zone hamper traditional archaeological recording techniques, and very often the complexity of structures, subtleties of topography, and distance from the shore can mean that planning of sites ignores the context of the wider landscape. This thesis provides a methodological approach to dealing with these issues, but also looks at how the data generated can go further into answering questions about the interaction of human technology with the dynamics of the landscape. Case studies at a number of sites throughout England and France are presented and used to examine various aspects of the technology and its application to coastal and intertidal archaeology.

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List of Accompanying Materials

Attached to this thesis is a DVD including samples of terrestrial laser scanning data from each of the case studies. These samples are provided in .pts format.

DECLARATION OF AUTHORSHIP

I, MICHAEL ALISTER LOBB declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Developing Terrestrial Laser Scanning of Threatened Coastal Archaeology Sites with Special Reference to Intertidal Structures

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission

Signed:...

Date:..

Acknowledgements

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My initial research on fishing structures benefitted tremendously from the collected articles and archives left by the late Dr Christopher Salisbury, whose fascination and dedication to the archaeology of the Trent valley and its fishing structures is a great source of inspiration.

The case studies within this thesis would have been impossible without the assistance and expertise of a wide range of individuals and companies. The site at Aust in Gloucestershire benefitted from the advice of Toby Catchpole of Gloucestershire County Council Archaeology Service and the local knowledge and experience of Martin and Richard Morgan of the Black Rock Lave Net Heritage Fishery. Involvement with the project at Léguer in Brittany was made possible by the kindness and hospitality of Vincent Bernard, Marie-Yvane Daire and Loïc Langouët of the Université de Rennes. The survey of the site at Emsworth, Hampshire drew on the knowledge and experience of Ann and Trevor Davies of Chichester and District Archaeology Society, who were kind enough to provide tea and biscuits on the foreshore. Dr Alasdair MacArthur provided training and technical support for the use of the spectroradiometer used at Emsworth from the NERC Field Spectroscopy Facility, University of Edinburgh. Involvement with the Medmerry Realignment Scheme on Selsey Bill, West Sussex was made possible through the work of Archaeology South East. In particular, thanks are due to the Project Manager Jon Sygrave, Cormac Duffy, Kristina Krawiec, Chris Russel and Jim Stevenson. The survey of the excavations at Low Hauxley was at the kind invitation of Dr Clive Waddington of Archaeological Research Services Ltd. who provided not only expertise and knowledge of the site, but also supported my involvement by providing hospitality and accommodation. The survey and site work were aided enormously through the assistance of Jim Brightman and Philippa Cockburn of Archaeological Research Services Ltd. In establishing a methodology and testing equipment, I was given access to a number of practice sites including Weald and Downland Museum, through the assistance of Julian Bell, sites in Jersey with the help Robert Waterhouse of the Société Jersiaise and Avalon Marshes roundhouse courtesy of Richard Brunning and Bob Mould of Somerset County Council.

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Last, but by no means least, I owe an enormous debt of gratitude to my supervisors, Professor Tony Brown and Dr Julian Leyland for their excellent guidance, support and patience during the course of my research.

To my parents for their eternal patience and support

and for Kris, for always

Definitions and Abbreviations

Please note: With reference to terrestrial laser scanning and associated technologies terminology and spelling used in this thesis are based on Newby (2012).

ADS	Archaeological Data Service
ALB	Airborne Laser Bathymetry
ALS	Airborne Laser Scanning
AONB	Area of Outstanding Natural Beauty
ARS Ltd.	Archaeological Research Services Ltd.
ASCII	American Standard Code for Information Interchange
BMME	Basses mers de mortes-eaux – French equivalent of MLWN
BMVE	Basses mer de vives-eaux – French equivalent of MLWS
CD	Chart Datum
CGI	Computer Generated Imagery
CIPA	Comité Internationale de Photogrammétrie Architecturale (International Committee for Architectural Photogrammetry)
CMM	Coordinate Measuring Machine
CW	Continuous wave
DEM	Digital elevation model
DSM	Digital surface model
DTM	Digital terrain model
EA	Environment Agency
EH	English Heritage
FOV	Field-of-View
GCCAS	Gloucestershire County Council Archaeology Service

GCR Geological Conservation Review

GIS Geographical Information System(s)

GNSS Global Navigation Satellite System(s)

GPR Ground-Penetrating Radar

GPS Global Positioning System

HAT Highest Astronomical Tide

IBM Image-Based Modelling

ICOMOS International Council on Monuments and Sites

INS Inertial Navigation System

ISPRS International Society for Photogrammetry and Remote Sensing

LAT Lowest Astronomical Tide

lidar Light Detection and Ranging

MHWN Mean High Water Neaps

MHWS Mean High Water Springs

MLS Mobile Laser Scanning

MLWN Mean Low Water Neaps

MLWS Mean Low Water Springs

MMS Mobile Mapping Systems

MSL Mean Sea Level

NIEA Northern Ireland Environment Agency

NM Niveau Moyen – French equivalent to MSL

OS Ordnance Survey

PBMA Plus basses mers astronomiques – French equivalent to LAT

PHMA Plus hautes mers astronomiques – French equivalent to HAT

PMME Pleines mers de mortes-eaux – French equivalent to MHWN

PMVE Pleines mers de vives-eaux – French equivalent to MHWS

PTM Polynomial Texture Mapping

RBM Range-Based Modelling

RCZAS Rapid Coastal Zone Assessment Survey

RSL Relative Sea Level

SCAPE Scottish Coastal Archaeology and Palaeo-Environmental Trust

SMP Shoreline Management Plan

SPA Special Protection Area

SSSI Site of Special Scientific Interest

TIN Triangulated Irregular Network

TLS Terrestrial Laser Scanning

TOF Time-of-flight

OTS Optical Triangulation Scanning

UAV Unmanned Aerial Vehicle

ZH Zéro hydrographique

Chapter 1: Introduction

1.1 Threatened Coastal Archaeology Sites

The modern study of coastal archaeological sites has its antecedents in the work of groups such as the Fenland Research Committee in the early 20th century (O'Sullivan 2001; see also Section 2.5 below) but has rapidly developed since the 1990s, with small research projects on individual sites giving way to larger scale assessments of archaeology within the coastal zone. Driving this has been the acknowledgement of the coastal zone, and in particular the intertidal area, as a valuable repository for archaeological material, with a high potential for the preservation of key organic remains, but with an equally high vulnerability to erosion. An increasing awareness of the mechanics of coastal change has fuelled academic interest in the coastal zone as a palimpsest of past sea level and shorelines whilst at the same time highlighting the relative frailty of the sites, and the threat presented by coastal erosion as both a natural process and in the context of climate change.

Academically as well as geographically, the coastal zone has fallen between terrestrial and marine archaeology as has been much understudied as a result. Recent attempts to identify and quantify archaeological sites and landscapes within the coastal zones of northwest Europe have revealed a much wider extent of heritage assets than previously thought (Murphy 2014). This added awareness of the richness of the archaeological resource coupled with the increased threat to the coast creates new challenges in, and demands new approaches to, the study of coastal archaeology

1.2 The Archaeology of Intertidal Structures

Within archaeology, the coastal zone is typically defined as including any site found between the lowest astronomical tide and up to 1km inland of the mean high spring water mark, although the exact definition of the 'coastal zone' is a matter of much debate (Gale 2000). The wide diversity of coastline in Britain means that this can include a diverse range of sites from post-medieval shipwrecks to Iron Age hill forts. This study will narrow in on those sites found in the intertidal zone, the area between the lowest and highest astronomical tides (See Figure 2 below). The intertidal zone itself contains a vast array of types of archaeological site, and indeed it has been noted that one of the challenges of working within the intertidal is the range of sites to be encountered (Bell 2013). This thesis will therefore further focus on those structures specifically built to exploit the resources of the intertidal zone, and in particular on structures built to capture or contain fish or other seafood. One of the underlying principles of the approach taken will be that intertidal archaeology, much like terrestrial and marine archaeology, needs to be understood as a landscape.

The term 'landscape archaeology' is perhaps an overused phrase, having been employed to refer to a number of approaches to archaeology, from scientific analysis of past environments to abstract approaches in understanding past belief systems. Indeed a study of intertidal fishing structures could be considered using a number of 'landscape' approaches; economic, political, cultural or environmental (see Figure 1). Similarly, other intertidal industries such as salt production, tidal milling or kelp production could be easily substituted into the same diagram.

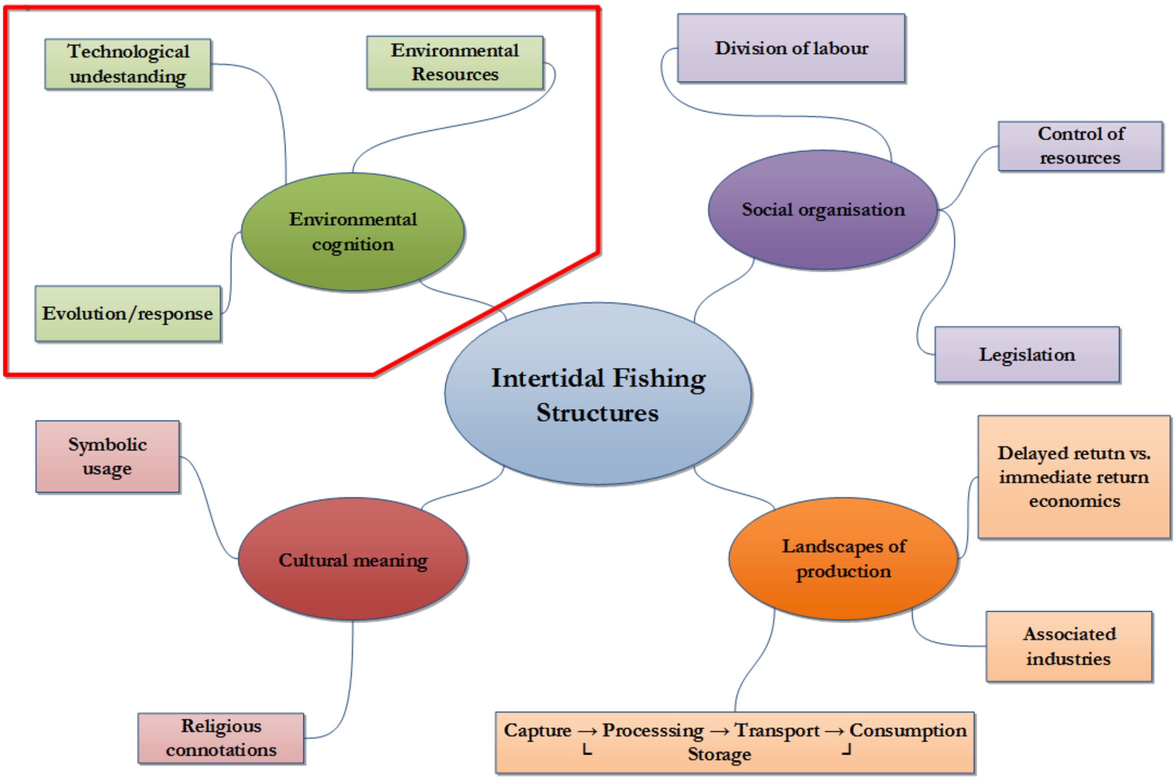

Figure 1 – Diagram showing the various methods and approaches that can be used to understand intertidal fishing structures. The use of technologies such as terrestrial laser scanning can be used to inform understanding of environmental cognition (highlighted by the red box).

Landscape approaches to intertidal archaeology sites have been attempted, with a strong emphasis on the study of inundated prehistoric landscapes, many of which use an approach similar to that seen in terrestrial archaeology. Landscape approaches to intertidal industries are by comparison rare, with the emphasis being firmly at the site level.

The application of 'landscape archaeology' in this thesis, however, will focus on the interrelation of the archaeology with the dynamics of the intertidal environment. Whilst past approaches to landscape were often polarised between environmental determinism or the perception of the landscape as mere backdrop to human activity, the interaction between landscape and culture is now accepted as being far more complex (Knapp and Ashmore 1999). Within the intertidal zone this interaction is particularly apparent, with the nature of landscape dictating the placement of sites, whilst in turn being changed by the human activity and industry which it facilitates.

Fishing structures are ubiquitous through global society, and have been in use from the Mesolithic to the present day. The near homogeneity of the materials and techniques used has led to a heavy reliance on ethnographic and historical parallels to explain their function and operation (e.g. Jenkins 1991; Gunda 1984) or on the limited information gathered from the small number of excavated sites (e.g. Losco-Bradley and Salisbury 1988; Godbold and Turner 1994). In many cases this has prejudiced not only the interpretation of sites and structures, but also influenced the approach to archaeological fieldwork, with morphological classification forming the basis of identification of sites. Current approaches to the recording of intertidal structures as a whole have a tendency to focus on the descriptive, with an emphasis on the material and constructional techniques used, and on dating the structure, rather than attempting any further level of interpretation.

Regardless of period, fishing structures are inevitably part of a much wider social and economic landscape, whether seasonally exploited providers of 'fall- back' foods, or industrial scale economic investments. Many questions remain about the means by which these structures were operated, their efficiency and the degree to which they contributed to wider fishing practices. Even simple questions about what types of fish they caught and in what number have frequently not been answered. Whilst this thesis in no way presumes to solve all of these issues, an underlying factor in all of them is the necessity of understanding the exact placement of the structures within their environment and landscape. The placement of such structures on coasts or within estuaries, the corresponding height of the tidal range, the alignment of the structure to the channel and tides, are all essential to understanding the function and efficiency of the structures, and in turn to inform our understanding of wider questions relating to past fishing practices. An approach that allows us to place these structures firmly within their landscapes is therefore essential (See Figure 1).

1.3 Surveying and Recording Intertidal Archaeology

The same environment that makes the intertidal zone such a rich resource for past industry also serves to hamper the recording and excavation of the archaeological remains. Continually changing water levels mean that terrestrial techniques of excavation and survey are highly limited by environmental conditions. The most obvious limitation is the accessibility of the archaeology, which can vary drastically, with sites at the high end of the tidal frame being accessible for several hours, whilst sites near the lowest astronomical tide mark may only appear for less than an hour a day at certain times of year. These periods of accessibility do not necessarily correspond to the hours of daylight, further limiting the ability to work on some sites. Sites can also be exposed for recording for only a short period before being covered by shifting deposits, or being scoured out by wave action. This continually changing landscape also makes the intertidal zone an extremely hazardous place to work, with additional risks posed to the field worker. The short exposure of the intertidal zone, its extents and the risks posed in fieldwork, have meant that large scale landscape survey has formed the backbone of recent approaches to identifying and quantifying intertidal archaeology. Aerial photography has been extensively used as a prospection tool for the identification of sites, although the majority of significant intertidal sites have in fact been chance discoveries, rather than being uncovered by systematic survey.

Once discovered, sites are most typically recorded using hand survey, the preferred method of recording wetland archaeology, and whilst site grids and baselines are typically established using GNSS, the majority of recording on intertidal sites is two dimensional in output. This is partly due to the limitations of the intertidal environment, but also because the truncation of sites and the subtlety of the foreshore itself can make the landscape seem deceptively flat, and thus reduce the perceived importance of recording in three dimensions.

Reports on intertidal archaeology sites rarely show structures in relation to their wider landscape, or place them within the tidal range or in relation to the ebb flow of the estuary or coast on which they are located. In short, intertidal archaeology is recorded at a site level, not at a landscape level, with little appreciation of how relation to local topography and conditions could aid in the interpretation of the archaeology, and inform long term conservation of sites.

1.4 The Development and Use of Terrestrial Laser Scanning

The development of terrestrial laser scanning has radically altered metric survey, not only by increasing the speed and accuracy by which data can be collected, but by altering the methodology for collecting data in the field. Whilst the fundamental principles of trigonometric survey remain the same, the volume and density of data collected through the use of TLS allows for a less selective process of survey in the field, and a greater range of options with the resulting datasets.

Within archaeology laser scanning as a whole has not just replaced earlier techniques, but has provided the opportunity for new types of analysis on landscapes, sites and artefacts (See Section

3.5 below). However, whilst guidance on best practice in the use of laser scanning within heritage has existed for nearly a decade (Barber and Mills 2007), methodological approaches have been slow to evolve past basic usage, and the use of data for anything beyond the production of basic two dimensional drawings or as a visual tool has been equally slow to develop. In part the development of TLS within archaeology has been hampered by a the expense of developing both the equipment and knowledge base, with a preference for more low cost technologies such as photogrammetry, or a reliance on traditional skills such as hand survey being used as a substitute.

1.5 Scope and Aims of this Research

The aim of this thesis is to develop a means of using terrestrial laser scanning to rapidly record intertidal structures within their immediate environs and to use that context to understand their construction and function. Measured survey of any kind requires a solid theoretical as well as a solid methodological approach, and the application of a different and new survey technology reflects a different and new approach to the archaeological study of these sites. Key to this is the underlying concept that structures built to exploit and utilise the resources of the intertidal zone are fully dependant on the dynamics of their immediate landscape. In order to understand their function, efficiency and life cycle we must therefore be able to place them firmly within their immediate landscape. Terrestrial laser scanning offers the ability to record not only the complexity of these structures, but also the subtleties of their surrounding topography at a high resolution, high speed and to a very high degree of accuracy.

Particular to this approach will be the emphasis on being able to locate such structures accurately within their tidal frame. Previous approaches have failed to fully appreciate the importance of the three-dimensional nature of intertidal sites, with not so much as a simple diagram to indicate their vertical placement in relation to the tidal frame, or an arrow to indicate the direction of the ebb tide. Whilst there are complexities in relating historic sites to the current relative sea level and tidal frame, nonetheless, these factors play a key role in understanding and reconstructing the function of intertidal structures in the past, as well as informing on the potential threat faced by the resource in the present and future.

At a broad level an appreciation of the dynamics of intertidal processes can help to inform the long term effects of coastal change on archaeological and palaeoenvironmental resources (See Chapter 8). Specifically, however, structures which were dependent on the intertidal zone to operate, through either the hydrodynamics (e.g. tide mills and salterns) or associated ecology (e.g. fishing structures, shellfish beds and kelp harvesting) of the intertidal environment, can best be understood through this approach, as it not only demonstrates the effect of the current environmental pressures, but has the added advantage of understanding and interpreting the archaeology in the context of its relative dynamics. TLS provides a level of data not previously gathered in the recording of intertidal sites, allowing a highly detailed recording of complex three dimensional structures to a high level of accuracy, and, through integration with other forms of metric survey, the placement of this information within a wider topographic landscape.

As has been seen above (see Section 1.3), the challenges of the intertidal zone hamper traditional archaeological recording techniques, and very often the complexity of structures, subtleties of topography, and distance from the shore can mean that planning ignores context of landscape. This thesis provides a methodological approach to dealing with these issues, but also looks at how the data generated can go further into answering questions about the interaction of human technology with the dynamics of the landscape. Most importantly, a key principle in analysing any archaeological site is first and foremost good data, and in particular metrically accurate survey (Pearson 2015). Terrestrial laser scanning allows for a less subjective recording of the site meaning that interpretation, and more importantly reinterpretation, is possible.

1.6 Chapter Layout

Following on from this introduction, Chapter 2 will present a comprehensive review of intertidal structures and archaeology, and examine how they relate to their wider landscape, an understanding of which forms the basis for the survey methodology developed in Chapter 3. Intertidal archaeology sites will also be discussed within the context of relative sea level, and in particular the tidal frame. Whilst the bulk of case studies within this thesis relate to fishing related structures, this chapter will also review the other industries which operated within the intertidal zone, principally salt production, tidal milling and waterfront archaeology, all of which are comparable to, and often mistaken for, fishing structures.

Chapter 3 will look at the development of terrestrial laser scanning as a technology, and place it within the wider suite of available survey technologies and approaches. The relative merits and shortcomings of the technology will be explored. The role of laser scanning in archaeology as a whole will be reviewed, and the potential for its application to intertidal archaeology will be assessed. Finally a general methodology for its use on the intertidal sites proposed.

Chapter 4 will demonstrate the integration of TLS data with existing topographical and archaeological datasets such as airborne laser scanning, orthophotography and bathymetry. The structures at Aust in the Severn Estuary, for which a large amount of topographical and archaeological survey data exists, will be used as an exemplum for the integration of TLS data, and an examination of the benefits of integrating different forms of data.

Chapter 5 will look the use of TLS survey in determining the function and relative chronologies of archaeological sites within an intertidal landscape. The structures at Servel and Le Yaudet in the Léguer estuary in Brittany will be presented and discussed, and the results of their TLS survey used to validate existing interpretations of their function and relative chronologies.

Chapter 6 will examine the usefulness of augmenting TLS data with additional imaging technology. In particular, the use of spectroradiometry in the survey of the site at Emsworth, Hampshire will be assessed, and the role of additional imagery in both scientific and representative visualisations discussed.

Chapter 7 will look at the use of TLS in the recording of a previously intertidal site now located in an area of reclaimed land. The excavation of the former intertidal structure at Selsey, West Sussex, involved the recording of the exposed structure using TLS. The results of the survey will be compared to traditional archaeological recording carried out on site and the relative merits of the two recording systems discussed.

Chapter 8 will present an approach for the long term monitoring of erosion at coastal archaeology sites using TLS, and present the results of survey of the archaeological and palaeoenvironmental deposits at Low Hauxley, Northumberland. Whilst being unrelated to the previous sites in terms of the nature of the archaeology, this chapter represents a case study for the use of comparative analysis for long term monitoring of archaeology that is applicable to all coastal and intertidal sites.

Chapter 9 will summarise the work carried out in this study, and will discuss what TLS adds to the study of intertidal archaeology sites, what it can and cannot do, and what additional technologies and methods we need to form a 'toolbox' for the recording of threatened coastal archaeology sites. The chapter will conclude by recommending best practice for the use of terrestrial laser scanning in the recording of threatened coastal archaeology sites.

Chapter 2: The Archaeology of Intertidal Structures

2.1 What is Intertidal Archaeology?

The intertidal zone can be defined as the area located between the highest astronomical tide (HAT) and the lowest astronomical tide (LAT) (Figure 2).

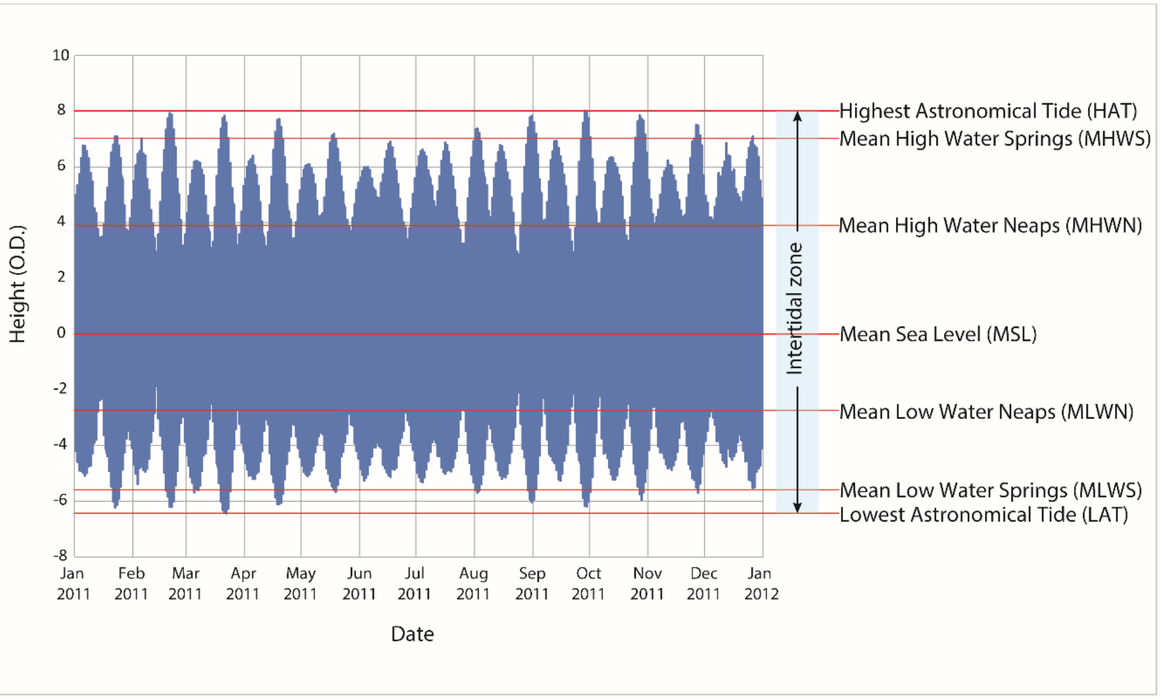

Figure 2 – Tides levels recorded at Avonmouth from January 2011 to January 2012, the cycle of neap and spring tides can be clearly seen over the course of the year. The mean levels are calculated by averaging these tidal levels.

Within the United Kingdom the past two decades have seen a growing awareness of this zone's importance as an archaeological landscape, with the development in the 1990s of new understandings and approaches to an area not covered by terrestrial or marine archaeology (Fulford *et al.* 1997; Aberg and Lewis 2000). This renewed interest has led to a drive to establish the nature and condition of archaeology within the intertidal zone, with heritage bodies in Scotland, England, Wales and Northern Ireland each adopting differing strategies to the quantification and assessment of intertidal archaeology. In Wales Cadw have produced coastal erosion surveys for each section of coast, and assessed the archaeological resources in the Coastal Survey of Wales (Davidson 2002). In Scotland, SCAPE (Scottish Coastal Archaeology and Palaeo-environment Trust) have released a series of reports on individual islands and sections of coast quantifying sites and reviewing the risk to coastal archaeology (SCAPE 2014). Within England, the ongoing English Heritage Rapid Coastal Zone Assessment Surveys

(RCZAS) have taken a similar approach, with the aim of producing a GIS package containing a comprehensive record of the coastal and intertidal sites. In Northern Ireland the Northern Ireland Environment Agency (NIEA) have begun publishing a series of monographs on the cultural maritime heritage (McErlean *et al.* 2002). Similar monographs have been produced in the Republic of Ireland (O'Sullivan 2001).

The importance of intertidal archaeology is now being recognised. Changes to relative sea level throughout the Holocene have meant that current shorelines can occupy a position either inland or seawards to those of any historical or archaeological period studied (see 2.2.3 below). The increased focus on intertidal archaeology, therefore, represents a growing recognition of the value of the foreshore as a potential source of heritage assets from marine, intertidal and terrestrial contexts.

Figure 3 - Late Mesolithic footprints within the intertidal peat beds on the foreshore at Low Hauxley, Northumberland (Eadie and Waddington 2013). Scale: 2m.

Changes in past relative sea level means that inundated land surfaces can survive within the intertidal zone without the distortion or destruction of subsequent occupation or modern development, allowing often fragile evidence to be better represented than on comparative terrestrial sites. In particular Mesolithic archaeology, which by its nature is difficult to differentiate from the remains of later periods, has a much sharper resolution in areas that have since become incorporated into the foreshore. However, sites within the Severn Estuary have revealed a much clearer picture of Mesolithic occupation than sites found on dry land and can include archaeological evidence not found elsewhere such as footprints, wooden artefacts and animal bone (Bell 2007a; Figure 3).

A higher degree of preservation occurs as the intertidal zone is in effect a large wetland area, and so has the advantages of wetland archaeology sites in preserving a much higher proportion of organic remains. Artefacts such as fishing traps and baskets, boats and timber structures from a wide range of archaeological time periods can be preserved within foreshore sediments. The preservation of organic remains also provides a large resource of palaeoenvironmental evidence, preserving earlier peat beds, submerged forests and sealed land surfaces, important not only for establishing past environments, but in contextualising human activity within them.

Mechanisms of erosion and deposition of sediment within the intertidal landscape mean that archaeological sites can be episodically uncovered or buried leading to urgency for immediate investigation and recording of sites before they are re-covered or destroyed. One of the drivers for the increased interest and activity in intertidal archaeology within the past few decades was the discovery of Seahenge, a previously unknown Bronze Age timber circle found at Holme Beach on the north Norfolk coast (Figure 4). The site was exposed through the erosion of the intertidal peat bed in which it was contained (Watson 2005). This threat to the archaeology also exposed the limitations in national strategies toward such sites and their preservation and mitigation, especially in light of the increasing threat from climate change and coastal erosion.

Figure 4 – 'Seahenge' - the timber circle exposed at the low tide mark on the beach at Holme-next-to-sea, Norfolk, excavated in 1999. Scale: 2m (© 1999 English Heritage)

Along with archaeological sites which have become associated with the intertidal zone through processes of erosion or accretion, numerous sites exist in their original location on the foreshore. In defining intertidal archaeology, a division can be made between archaeology *of* the intertidal compared with archaeology *in* the intertidal. A clear definition can be made between those sites that, through a range of processes, have been moved to a position within the tidal frame and those sites that were purposely located within the intertidal zone in order to exploit it. Thus sites which have suffered from inundation, such as Mesolithic occupation areas, submerged forests and peat beds and medieval settlement sites such as Dunham or Winchelsea which have fallen prey to coastal erosion can be considered sites *in* the intertidal, whilst deliberate constructions within this zone, such as fixed fishing structures, wharfs and salterns can be considered archaeology *of* the intertidal. The bulk of this thesis will focus on the latter type of site, and in particular those that are concerned with fishing.

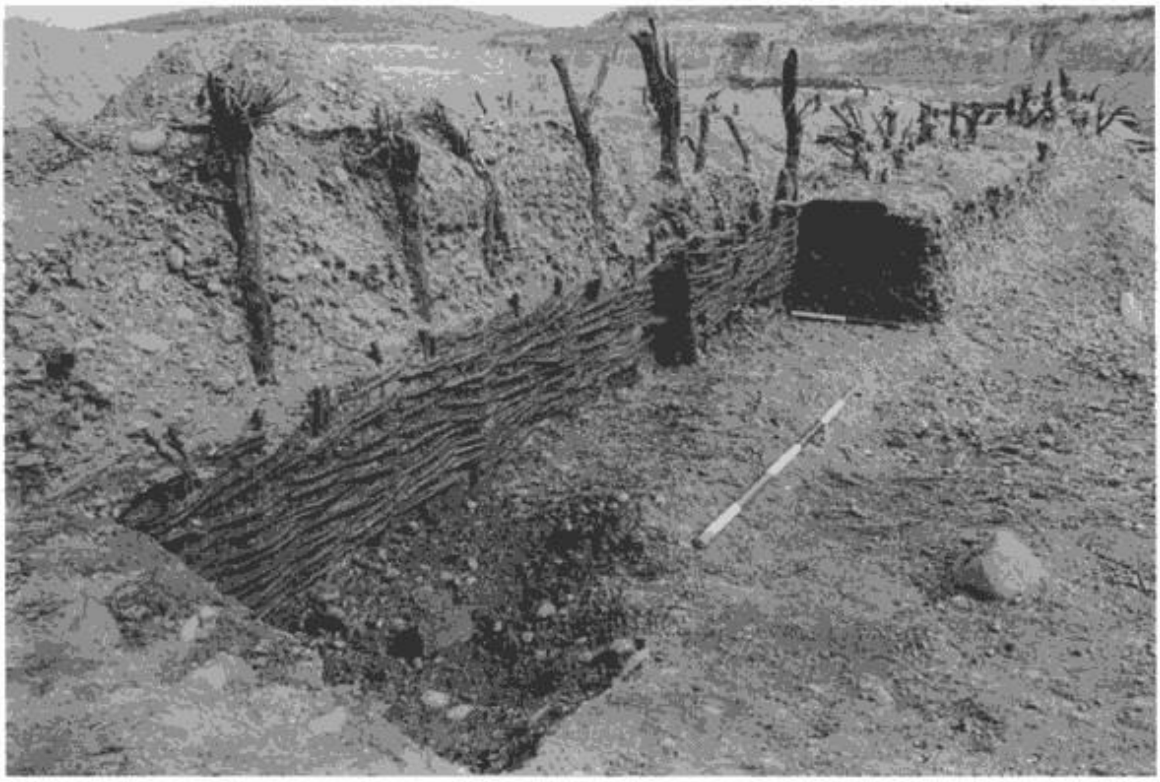

Figure 5 – The remains of a Norman fish weir excavated from a palaeochannel of the Trent at Colwick, Nottinghamshire in 1978 Scale: 2m (Losco-Bradley and Salisbury 1988)

The archaeology of the intertidal zone can therefore also be present within areas of reclaimed land, or buried beneath coastal sedimentary deposits. Archaeological excavations on land can thus expose archaeological structures and finds previously contained within an historic intertidal zone. The extensive historical reclamation and drainage which occurred in such areas as the East Anglian fens or the Somerset Levels both obscures and preserves earlier estuarine, intertidal and tidal archaeology (Rippon 1997). Within terrestrial archaeology palaeochannels provide a repository for archaeological and palaeoenvironmental information on past adaptation and exploitation of waterways, such as, bridges, canals and fishweirs (Figure 5).

In much the same way, the buried remains of estuarine and marshland environments provide similar information about intertidal archaeology. Sites such as Must Farm, Cambridgeshire, Medmerry, West Sussex and Steart Flats, Somerset have all recently produced well-preserved intertidal fishing structures from a wide range of prehistoric and historic contexts.

2.2 Intertidal Archaeology and Relative Sea Level

Sites that make use of, or deliberately exploit, the intertidal zone must be understood within the context of sea level at the time of their construction and their subsequent usage. However, relative sea level (the position of the sea relative to the land at a given location) is not straightforward and is dependent on a number of factors.

2.2.1 Processes of Sea Level Change

Two major factors dictate overall sea level, eustasy and isostasy. Eustasy refers to the absolute water-surface level. Eustatic change is caused by an increase or decrease in this volume of water most notably through glacio-eustasy, where sea-water is locked up or released through glacial accumulation or glacial release (Pethick 1984).

Isostasy refers to changes in the absolute level of the land, principally caused by tectonic activity or crustal loading. As with eustasy, glaciation is a primary cause, with glacio-isostasy resulting from the addition or removal of large volumes of ice from the land surface. The weight of glacial ice causes areas of land to be depressed to different depths dependent on the amount of ice covering them, in general up to one third of the maximum ice thickness. The removal of this ice during inter-glacial thaw leads to isostatic rebound, when the land mass previously covered by ice begins to rise. A similar process known as hydro-isostasy takes place beneath the sea where the varying weight of water on the ocean floor results in either depression or rebound (Pethick 1984).

2.2.2 Relative Sea Level and the Tidal Frame

Relative sea level change at a given location is therefore principally determined by a combination of eustasy and isostasy. However, these processes are further augmented by a wide range of localised factors which can include tidal variations, temperature, pressure, river discharge, upwelling from deep sea currents, and local changes in sea-water salinity (Pethick 1984), all of which have an impact on the sea level at a specific location (Figure 6).

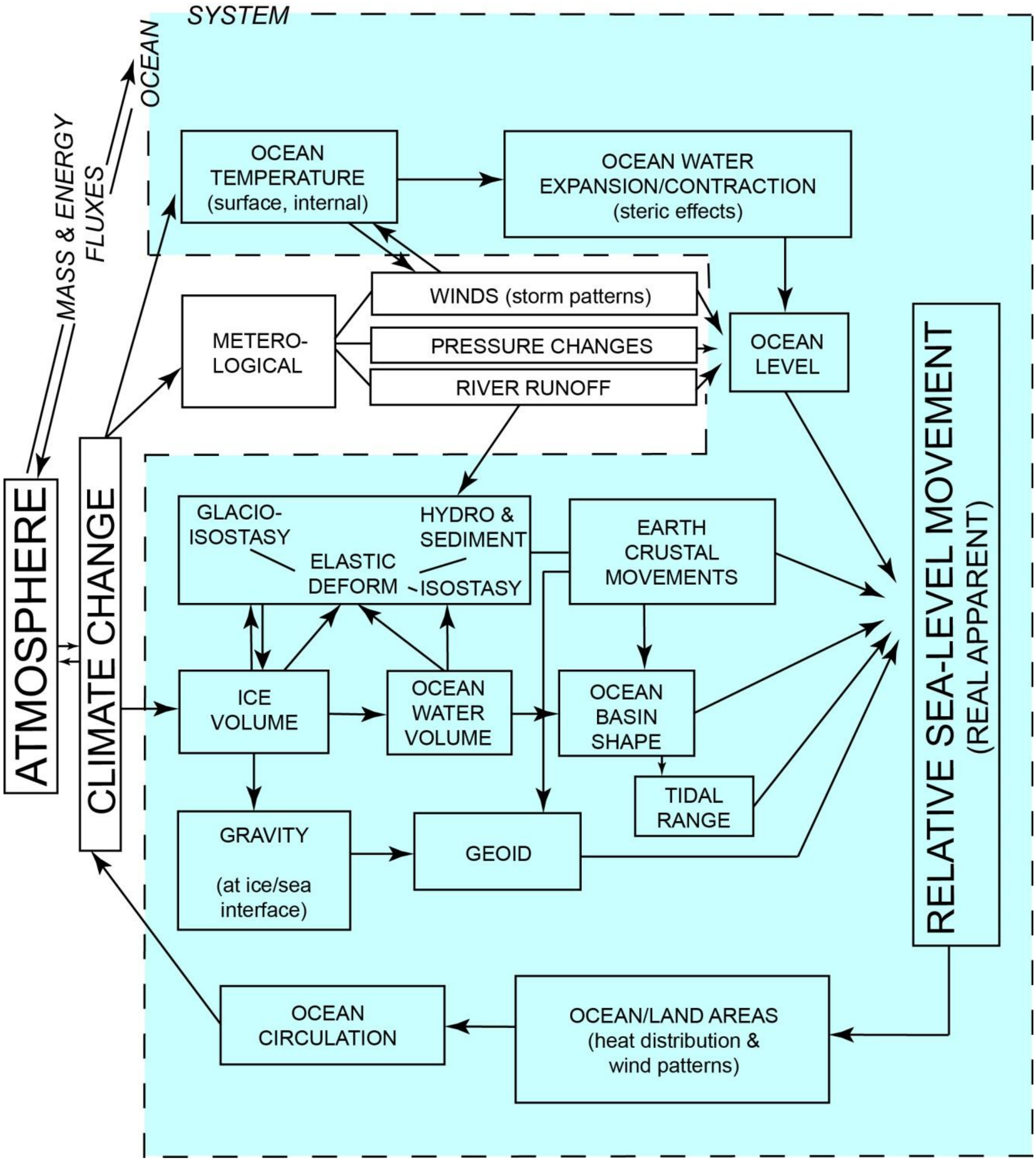

Figure 6 – Diagram illustrating the interrelation of factors influencing relative sea level (after McGrail 1990).

Relative sea level is intrinsically linked to the tidal range, the vertical difference between the high and low tide. This difference is dictated by a range of coastal drivers and in turn plays a part in determining the nature of coastal landforms (Clayton 2003). Within Britain the tidal range varies from under a metre in the Outer Hebrides to over 12m in the Severn Estuary (Shennan 1989), creating wide variation in coastal geology and geomorphology.

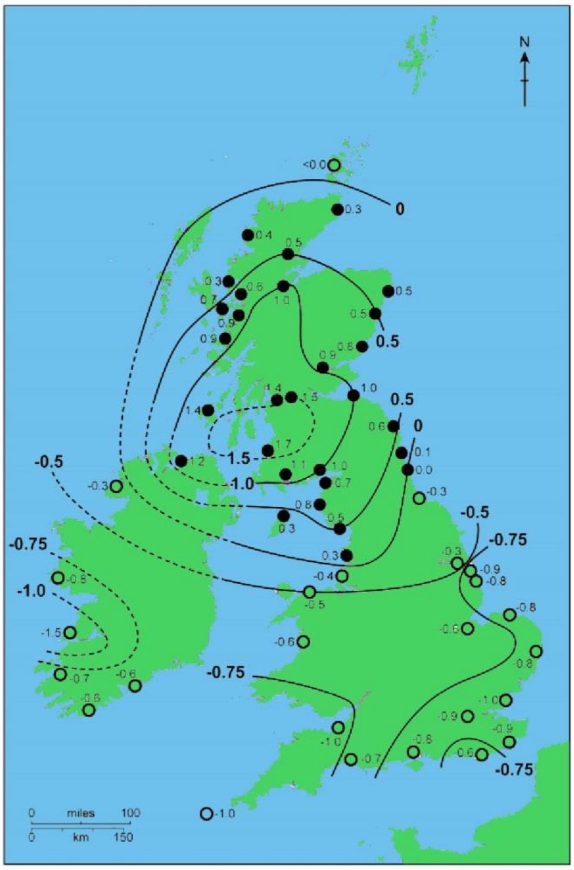

Figure 7 - RSL changes (mm/yr[1]) in the British Isles - positive values indicate uplift or sea-level fall whilst negative values indicate sea-level rise or relative land subsidence (Gehrels 2010)

2.2.3 Implications for Archaeological Sites

Glacio-isostatic rebound has led to uplift of the landscape of northern England and mainland Scotland whilst southern and south-eastern England are sinking, although the rate of this change has steadily decreased throughout the Holocene (Shennan 1989). This varying relationship between land and overall sea level throughout the British Isles serves to confuse the archaeological narrative. This can be rectified by correlating the height of coastal features of the same date to create a map of land/sea level change, with lines linking these features to create isobases (Pethick 1984). These isobases allow for the mapping of eustatic and isostatic change to create a base map for overall sea level change through the Holocene. This information can then be used to predict the current rate of the land and sea level change at a given location (Figure 7).

Changes in relative sea level, however, act not only vertically, but also horizontally, leading to inundation or regression of coastlines. A positive relative sea level change, which would involve a rise in sea level or a fall in land level, would in most cases lead to a transgression of the sea onto low-lying land. Conversely a negative relative sea level change, involving a fall in sea level or a rise in land level would produce a horizontal regression, causing new land to appear (Pethick 1984) . Within archaeology, the effects of these changes are perhaps best exemplified by submerged landscapes such as Doggerland, which provides an extreme example of the effects of marine transgression on an archaeological landscape (Gaffney *et al.* 2009).

Of equal importance to the understanding of intertidal archaeological sites is the tidal range at a given location. As noted above, tidal range plays a role in defining the nature of the coast, and so in defining both the resources available and the manner in which they may be exploited. Deep natural harbours allow for the creation of ports, whilst large expanses of mudflat allow for the development of intertidal fishing. Tidal range changes due to number of factors both natural and anthropogenic (Shennan and Horton 2002), and in turn impacts on the suitability of a given site for specific human activities. The understanding of intertidal archaeology sites therefore requires an understanding of both the contemporary relative sea level and tidal range.

2.2.4 Intertidal Archaeology Sites as Markers for Relative Sea Level

Sites designed to exploit the intertidal zone have a fixed relationship to their relative sea level, and in particular to the local tidal range. Those found outside the boundary between HAT and LAT, either below water or on land, are indicative of a definite change in RSL. Sites that appear at the extremities of the intertidal zone may likewise represent a shift in RSL, but may equally represent an intermittent exploitation of specific tides. Whilst the overall RSL at a given site is important, Everard (1980) has argued that the use of mean tide level (either MHT or MHST) rather than mean sea level is more useful as it is more closely related to tidal range.

The potential efficiency of an intertidal structure, and thereby its maximum potential output, can be defined by both the depth of its immersion and the length of time for which it is accessible between immersions. Therefore, knowledge of the relative sea level and tidal range would dictate the efficiency of the structure. However, such an interpretation also necessitates an understanding of how structures were operated by the individual societies, and how they operated within a wider landscape of production (See 2.10 below).

2.3 Policy and Protection of Coastal Archaeology Sites

Where they are known to exist, intertidal archaeological sites and monuments are covered by the same protections afforded to terrestrial sites, although the processes affecting them can be radically different. In addition, the intertidal zone is frequently subject to non-archaeological protections that have a direct impact on the study and preservation of heritage sites. Estuarine environments are often sites of ecological or environmental conservation, and as such can be designated as World Heritage Sites, Ramsar sites, SSSI, and AONB, to mention but a few. These additional designations can have a direct impact upon the archaeology, ranging from simple issues of access to sites, to large-scale changes to the water table and geochemistry.

2.4 Threats to Intertidal Archaeology

The prime threat to intertidal archaeology sites are naturally occurring coastal processes. In particular coastal erosion leads to the scouring out of deposits containing archaeological and palaeoenvironmental material. There is a certain irony in the fact that the processes of coastal erosion very often facilitate the discovery of previously unknown archaeological sites whilst at the same time posing a direct threat to them (Chapman *et al.* 2001). The high dynamism and rate of erosion means that a rapid and coherent response to threatened archaeological sites is essential. In particular, within estuaries, sites affected by bank erosion often decay at an exponential rate due to 'edge effect' (Chapman *et al.* 2001). Similarly, sites situated on cliffs such as hilltop or promontory forts, are often undercut by wave action, and are destroyed by episodic collapse rather than by a steady and predictable rate of erosion.

The scale of coastal erosion within the past millennium alone illustrates the massive impact on not only intertidal but also terrestrial archaeology. On the east Yorkshire coast, the Domesday book names 16 settlements now lost to the sea (Rackham 1989). Norfolk and Suffolk have both lost medieval churches and entire villages, such as those at Dunwich or Winchelsea, due to coastal retreat. On the south coast of England at Selsey Bill, an estimated 4m of land per year has been lost to the sea since 1700AD (Whittaker pers. comm.).

In addition to erosion, the accumulation/accretion of sedimentary deposits can lead to the burying of archaeological sites. Whilst this in itself does not lead to the destruction of the material, creating instead the natural equivalent of preservation *in situ*, the burial of archaeological deposits leads to a loss of opportunity to sample or record sites and artefacts. Archaeological sites have been reported disappearing below sediment only to reappear from shifting sands over a century later. The burial of such deposits, especially in areas of reclamation, means that it is impossible to quantify the survival of more delicate materials, with the potential for drying out and decay along with changes to the hydrology and geo-chemistry of the soil.

Alongside natural threats to coastal archaeology, sit a range of anthropogenic practices that affect the intertidal zone. The extraction and mining of aggregates, dredging of river channels and harbours, and the reclamation of land from the sea have affected the coastal belt and intertidal zone for the past two thousand years

2.5 Landscape Approaches to Intertidal Archaeology

The first systematic landscape-style approach to intertidal archaeology is generally taken to be the study of the Essex coastline in the 1930s by the Fenland Research Committee (see Warren *et al.* 1936). This study was notable in not seeking to simply describe the artefacts found, but to relate the land surface on which they were located to wider landscape change. By the 1970s and 1980s the emergence of large scale wetland investigations such as the Somerset Levels and Fenland projects led to both an interest in intertidal wetlands and the development of the methodologies and expertise with which to approach them (Bowden 1999). By the late 1980s and early 1990s these approaches had been fully integrated into both large scale landscape investigations such as the Humber Wetlands Project (Van de Noort 2004) which studied vast areas of intertidal and estuarine archaeology, as well as into groups such as the Severn Estuary Levels Research Committee (SELRC), which formed to provide a forum and overarching research framework for a number of smaller coastal projects within the Severn Estuary. The early 2000s saw the implementation of the National Mapping Program by English Heritage, which provided the model and framework for the Rapid Coastal Zone Assessment Surveys (RCZAS), which aimed to record all archaeological sites from the low water mark to 1km inland around the entirety of the English coastline. This systematic survey of the coastline was matched in Wales with a number of regional coastal surveys funded by Cadw, which were summarised in a thematic summary volume (Davidson 2002). Likewise in Scotland the SCAPE project focused in depth on individual stretches of coastline and island groups (SCAPE 2014). More recently, coastal realignment schemes carried out by the Environment Agency have provided an opportunity to investigate large swathes of landscape prior to redevelopment. The investigation and recording of stretches of estuary and coast has moved to continual monitoring of coastal areas through the engagement of local communities and special interest groups. Outreach projects such as Shorewatch in Scotland (SCAPE 2016) and CITiZAN in England (CITiZAN 2016) have aimed to engage local communities with their coastline and train them in the methods necessary to record intertidal archaeology. This approach has the benefit of mobilising a large number of people who are able to report both the emergence of new sites as the coastline changes, and record the erosion or burial of known sites within their local area.

Whilst landscape characterisations have taken place around almost the entire coastline of the United Kingdom, very few attempts have yet been made to characterise coastal or intertidal archaeology at a national or even international level. Several general criticisms can be levelled at the approaches taken in earlier studies of coastal and intertidal archaeology landscapes. Firstly, most landscape approaches to intertidal archaeology tend to confine themselves within political or physical borders, and very few coastal studies have linked their stretch of coast with corresponding coastlines across the water. For example, very clear similarities in technologies exist between fishing practices on the Gwent and Gloucestershire shorelines of the Severn Estuary, yet most studies, including those that are not commissioned by local authority or government bodies, have limited themselves to one side of the Estuary. Similarly, intertidal structures and practices in northwest France and southwest England show remarkable parallels, but as yet no detailed study has been carried out into this relationship. To fully understand the development and spread of intertidal practices and technologies, parallels need to be drawn in across both political and physical borders. Likewise, there has been only a limited attempt to relate different types of coastal and intertidal sites to their underlying geomorphology and geology, which defines not only the availability of materials used in creating intertidal structures, but also influences the hydrological factors key to their operation. Establishment of this relationship at individual sites could help to chart wider patterns in the type of industries and structures linked to different coastal and tidal morphologies. Finally, both of the above approaches could be used to help develop a predictive model for areas of coastline that have yet to be investigated. Most of the surveys commissioned by English Heritage, Cadw and Historic Scotland provided a GIS database of results. These could easily be integrated to allow analysis of regional and national patterns in intertidal and coastal archaeology and help to predict the types of technologies and practices that could be expected in specific stretches of coast.

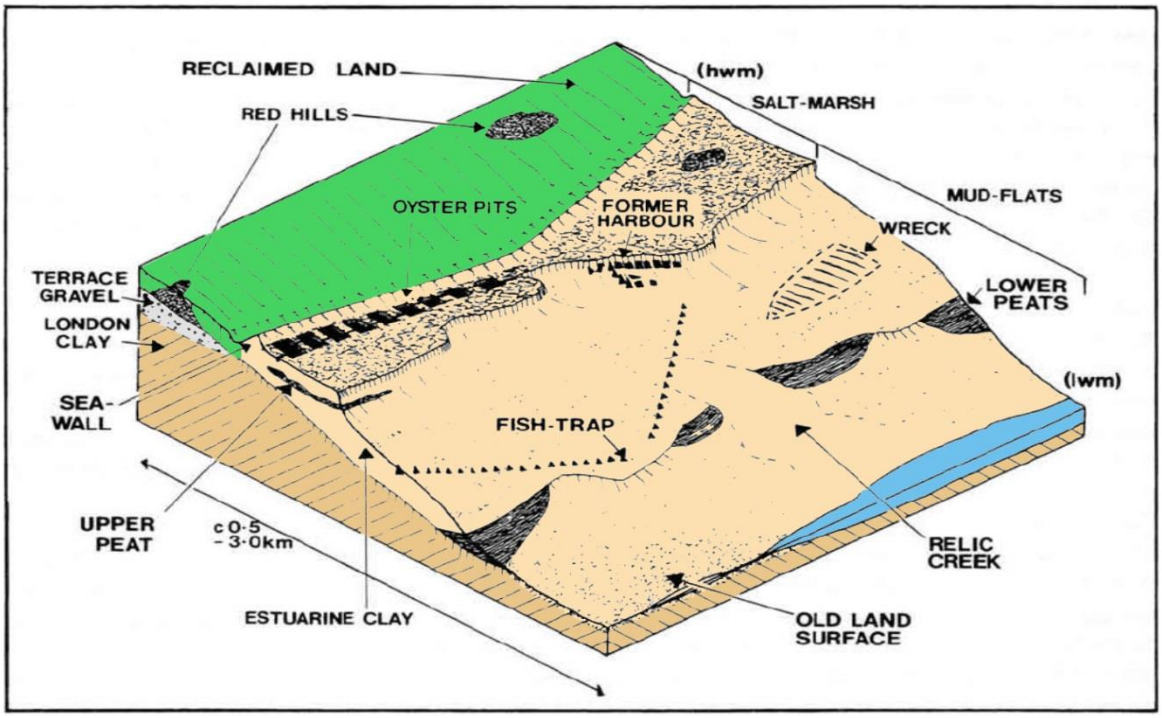

Figure 8 - Potential type and location of archaeological sites within the intertidal zone (Strachan 1995)

2.6 Intertidal Structures – A Past Industrial Landscape

Much of the modern day coastal and intertidal zone is a peaceful and picturesque landscape, and as much as this may appear natural or semi-natural, instead it represents a deliberate exploitation of the landscape for alternative industries and social priorities, such as tourism, development and environmental offsetting. By contrast, the coastal and intertidal zone of the past focussed on the utilisation of the landscape as a zone of industrial exploitation. The sea provides a resource for raw materials and minerals such as salt, sands and seaweed, as well as foodstuffs in the form of fish, shellfish and plants, and as a consequence specific industries and technologies have developed within the intertidal zone reflecting the demand for these products. It is important to understand the types of structure designed to exploit the intertidal zone as there are many similarities between them both on the materials and technologies used in their construction and in their design, and they can often fulfil more than one function. Different types of intertidal structure exploit different parts of the tidal range, so being able to identify the function of the structure can tell us more about relative sea level, likewise understanding the tidal range can help to identify the function of structures.

2.6.1 Fallback industries? Seasonality, Choice and Interdependence of Intertidal Structures

The ranges of industries that occur within the intertidal zone are subject to drivers that define their application and extent. Seasonality has a large impact on most intertidal activities; fishing is limited due to both the seasonal movement of shoals but also the effects of increased storminess over the winter months. Likewise, with salt production, seasonal factors place a physical limitation on the industry (see Figure 11 below). Within the fishing industry, the diversification of technologies and approaches meant that different strategies could be employed at different times of year to take advantages of seasonal patterns of fish migration. Along with physical and limitations on the use of the intertidal zone, economic considerations have also played a large part. The specialisation of coastal communities into a single industry was almost impossible until the modern period (Pawley 1984) with most coastal communities engaging in both fishing and farming until at least the early 16th century (Fox 2001). In many cases there is a strong overlap between these factors, for example tidal mills fell out of favour by the 13th century due to a long period of increased storminess that raised the economic cost of repairing or replacing them (Holt 2000; Fulford *et al.* 1997). Likewise, specialisation in pilchard fishing in Devon and Cornwall in the 19th century was driven by demand, but facilitated by the geographic range of the shoals, which was limited to the very southwest of England (Pounds 1944). Other more intangible factors also exist which influence the activity within the intertidal zone. The perceived lack of fishing within Iron Age Britain is often taken to be driven by a cultural taboo against fish consumption (Dobney and Ervynck 2007), but could as easily be attributed to the industrialisation of the coast for salt production and saltmarsh grazing during this period. It is important to remember that whilst there are constrictive factors in the selection of activity within the intertidal zone, which may be environmental, ecological, economic or cultural there is still a degree of conscious choice in the activity chosen (Rippon 2000). An examination of intertidal structures must therefore encompass a multi-disciplinary approach to understand the interrelation of the various drivers.

2.6.2 Salterns and Salt Production

Since the 19th century almost all the salt produced in the UK has been extracted from underground mineral deposits in Cheshire, from salt beds covering an area of over 350 sq. miles (Bestwick 1975). Prior to the 19th century within Europe salt was produced through four main processes; mineral extraction through mining, evaporation of sea-water, evaporation of water from brine springs and the burning of salt rich vegetation (Alexander 1982). The last is as yet unknown in Britain, but occurs nearby in Holland during the medieval period (Fawn *et al.* 1990). The remaining three processes exist within the archaeological record in Britain, at times overlapping in their application. Salt, as a soluble mineral, leaves no trace in the archaeological record, except in very dry countries (Woodiwiss 1992). The extents of past industry, therefore, can only be established by mapping salt production sites.

Although the consumption of some salt is essential to the human diet most of this is ingested through the consumption of meat and salt-rich plants and, with the exception of extreme circumstances, there is no need for additional salt in the diet (Carter 1975). The purpose of salt production, therefore, lies in its additional attributes, primarily as that of a preservative. Subsequently, salterns are very often intentionally coincident with production sites for meat and fish, both of which are commonly located in the coastal belt. In addition to preserving meat and fish, salt was a vital component of cheese-making (Lane and Morris 2001), tanning (Bradley 1992) and was valued in the Roman period for its antiseptic properties (Lane and Morris 2001).

Prior to 500 B.C. most salt-production in Europe appears to been based upon inland mineral extraction or evaporation of water from brine springs, with a subsequent move to the production of salt from coastal sites (Alexander 1982, see Figure 9 below).

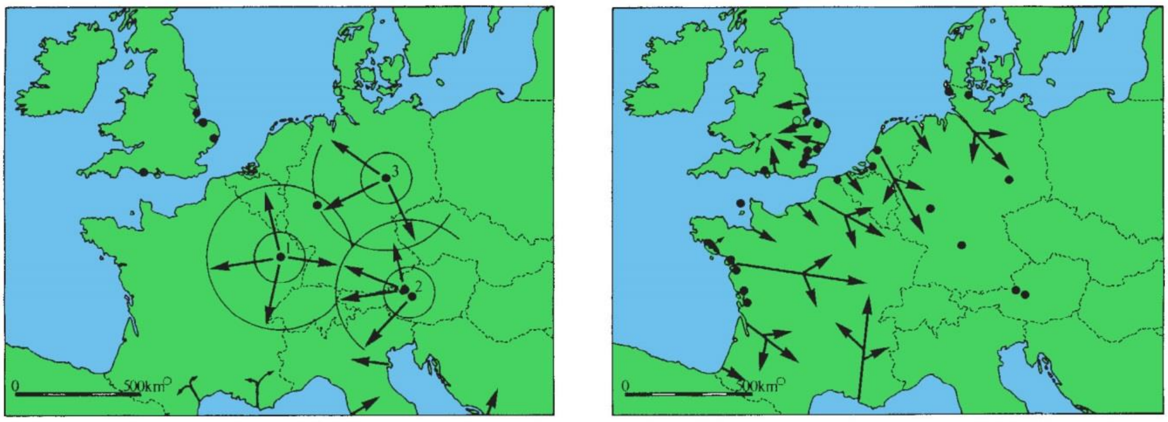

Figure 9 - The suggested pattern of salt production and distribution in western and central Europe before 500 BC (left) and after 500 BC (right) (Alexander 1982)

This shift has been linked to the migration of peoples across Europe during this period (Alexander 1982) and coincides with the development of the La Tène culture, which may have disrupted or changed previous trade networks. Although it is presumed that salt production occurred from at least the Neolithic in Britain, the earliest known evidence is from briquetage dating to the Middle Bronze Age (Bradley 1975). However, within this period the only evidence comes from artefactual evidence, with no salt-making sites identified (Lane and Morris 2001).

The first distinct period of salt-making in England occurs from the 2nd century B.C. into 1st century A.D. (De Brisay and Evans 1975) and is represented by the so-called 'Red Hills'. Although this term is specific to the mounds in Essex and Kent, and refers to the discolouration of the earth through burning, similar mounds and structures exist throughout England, with over 300 sites in Essex (Fawn *et al.* 1990) and Kent (Miles 1975), 300 similar structures in Lincolnshire and Norfolk Fens (Lane and Morris 2001), and numerous sites scattered through the Somerset Levels (Rippon and Cameron 2006). During this period there is virtually no change in the technology used, implying continuity in practice through the Iron Age to Romano-British transition (Bradley 1992).

Only a small percentage of known sites have been excavated due to their sheer scale, and the lack of substantial archaeological remains within each monument. Those that have been excavated are consistent in terms of structure. The salterns consist of mounds of reddened earth mixed with charcoal and briquetage (a crude form of pottery mainly associated with salt production). Production occurred close to the high water mark. A channel was dug to bring salt water up to production site (Bradley 1992), the salt water was then allowed to settle in clay lined pits, and the subsequent brine heated in briquetage pans to allow crystallization of the salt (De Brisay and Evans 1975; Figure 9). On the continent similar sites are known, with over 130 salt-making sites along the Brittany coast, most dating to the end of the La Tène period (Daire *et al.* 2011) and similar sites are found at the mouth of the Loire (Tessier 1974). Likewise, sites have been reported on the Belgian coast (Thoen 1975) and Channel Islands (Riehm 1961). Slight variations in salt production occur in Britain during this period, though mostly at inland sites such as Droitwich and Nantwich, which produced salt from brine springs. Within the coastal belt, a slightly different structure has been uncovered on a 2nd century A.D. site near St. Keverne in Cornwall, 2nd century A.D. site, where ovens were used to heat a stone floor, upon which evaporation vessels were placed (Peacock 1969).

Figure 10 – An artist's reconstruction of the Essex 'Red Hills', the by-product of industrial scale salt-making within the intertidal zone (© Essex County Council 2006)

The end of this form of salt production occurs in the first couple of centuries A.D. and numerous theories have been put forward for its decline. Economic reasons for the demise of the red hills have been asserted, with the need for salt as a trade commodity being replaced by the introduction of coinage (Bradley 1992). The introduction of the villa system may also have contributed to their decline, with the waterfront areas at sites such as Chichester Harbour being cleared for alternate use by the villa at Fishbourne (Bradley 1975). The evolution of new forms of technology may also have been instrumental in the decline of the industry, with the introduction of lead pans, and the greater use of inland resources such as the mineral deposits in Cheshire and brine springs in Worcestershire. Certainly there is no evidence of Iron Age use of these deposits, so it may be that they were Roman introductions (Bestwick 1975). An environmental determinant may also be suggested, there is a known rise in relative sea level around the coast of southern England in the 3rd century A.D. (Miles 1975), and evidence from the Somerset Levels shows the subsequent regression of the coastal salt-making sites to saltmarsh from the 4th century onwards (Brunning 2006).

By the time of Conquest, numerous salterns are listed in the Domesday Book, implying a widespread salt industry in the Saxon period (Darby 1952), and the industry appears to have been substantial enough to have caused the establishment of entire towns (Owen 1979). In the later medieval period, coastal salterns again take the form of large mounds, this time up to 1.21 acres (4897 m^2) in size and up to 20 feet (6.1m) high (Rudkin 1975). Medieval salterns differ in form to earlier examples; the mounds are surrounded by a ditch, and have pits in the top. They are constructed of alluvium and not red earth, and the sites are built on the alluvium not on dry land, presumably to allow the high tide to more easily fill the settling tanks. The mounds appear to be there to raise the evaporation pans above flood level (Fawn *et al.* 1990). However, documentary sources describe the collection of salt rich intertidal sands referred to as 'sleech' (Martin 1975) or 'mudefang' (Fawn *et al.* 1990). This was used to enrich the brine and may have contributed to the formation of the mounds. These industrial waste heaps occurred all around the Wash up until about 1400 (Owen 1979) and were substantial enough to form a more permanent part of the landscape, with houses and even Medieval churches built on top of abandoned salt-processing mounds (Owen 1975).

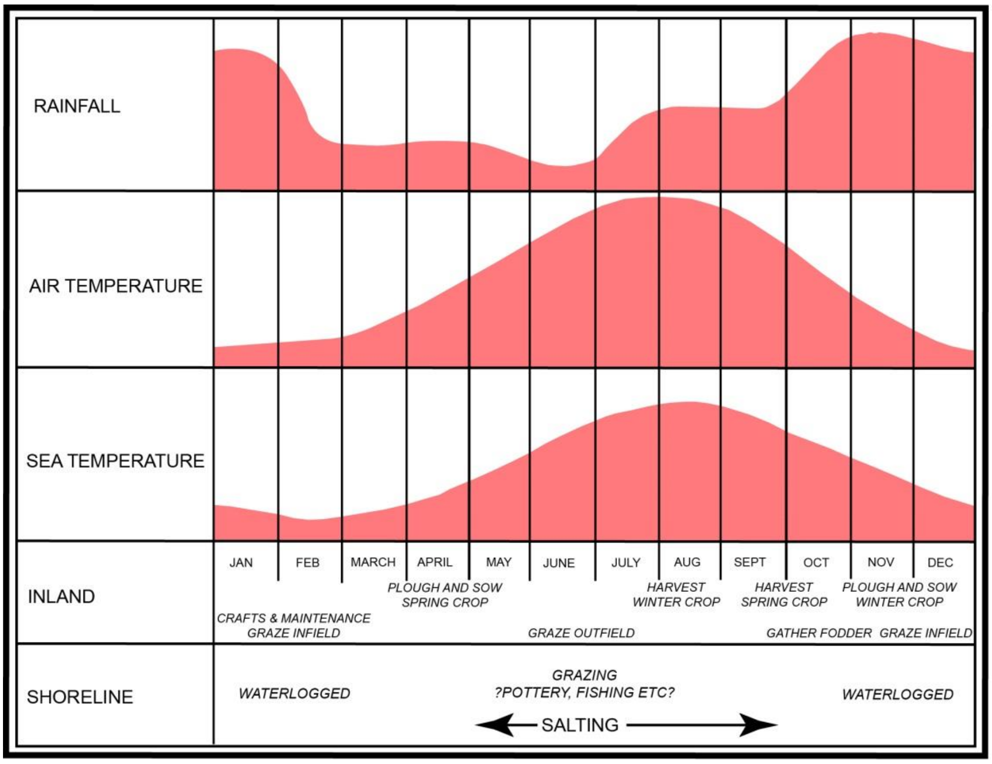

Figure 11 - Graph showing the comparative seasonality of environmental factors required for the production of salt (Bradley 1975)

By 1600, the production of salt in Britain had been greatly impacted upon by taxation, with salt produced in England subject to levies that did not exist in Scotland or Ireland (Rudkin 1975). At the end of the 17th century the vast extent of the Cheshire rock salt deposits at Northwich, Nantwich and Middlewich, which had been centres of salt production since the 11th century (Bestwick 1975), moved production of salt away from the coast. Coastal sites continued in use, however, with the development of a new technique referred to as 'salt on salt', by which mined bay or rock salt was dissolved in sea water, creating richer brine (Fawn *et al.* 1990). This form of production occurred mainly on the south coast, where sites such as Lymington in Hampshire, which had used solar pans since the 13th century (Rudkin 1975), adapted the 'salt on salt' method, utilising both solar and coal-fuelled evaporation to create salt (Fawn *et al.* 1990). Fuel was shipped to the south coast from as far afield as Northumberland and Cumbria to fuel the evaporation pans (Martin 1975). The identification of some salt production sites is sometimes problematic as large evaporation ponds have been reused as tide mills, fish-traps or even marinas.

Regardless of the technology used certain conditions are essential for the coastal production of salt (Bradley 1975). These are:

1. a period of high water followed by a series of neap tides
2. an optimum sea and air temperature
3. prolonged sunshine and limited rainfall

Until the 17th century, these factors limited the production of salt on the coast to the summer period, making salt production a seasonal activity (See Figure 11). The production of salt therefore falls into a much wider sphere of activities, such as farming, fishing and pottery production. In the Iron Age salt held an economic value as currency, with the size and shape of briquetage containers used to standardise the value of salt blocks (Bradley 1975). In the later Roman period salt production became part of a much wider trade network, with the refocusing of the industry inland to a much smaller area of the country. There is a strong possibility that the church was involved at this stage, possibly as early as the 4th century A.D. (Penney and Shotter 1996). The apportionment of the foreshore to secular and religious landowners in the medieval period meant in turn the apportionment of salt production (Owen 1979). The influence of such landowners in the salt industry can be paralleled with the distribution and control of fisheries (See below 2.8.7). Documents referring to the establishment of monastic houses in the post-Conquest period establish rights to gather salt and to cut peat to produce the salt, and document the building of sea dykes to protect salt-producing areas (Martin 1975).

The low-lying location of coastal salterns and their positioning as close as possible to the high tide mark has made them greatly susceptible to coastal erosion. Although in some areas there is a good survival of sites in areas with low energy tides (Bradley 1975), an indeterminate, but nonetheless substantial number have been lost around the East Anglian coast since the Roman period (Lane and Morris 2001). In other areas, where a rise in relative sea level has led to an accretion of sediment, sites have disappeared under alluvium (Fawn *et al.* 1990), reappearing only after significant storms or scours (

Figure 12 - The remains of intertidal salterns, most likely of Iron Age date, at Sutton-on-Sea, Lincolnshire, revealed after the removal of overlying sediments by the 1953 winter storms (Rudkin 1975)

).

In areas of land reclaimed by drainage, such as the Somerset Levels and the East Anglian Fens, sites once located near the high tide mark in the Iron Age and Romano-British period are now located on dry land (Rippon and Cameron 2006), meaning they have been susceptible to ploughing out or being used as a source of material to lighten clays (Fawn *et al.* 1990).

Figure 12 - The remains of intertidal salterns, most likely of Iron Age date, at Sutton-on-Sea, Lincolnshire, revealed after the removal of overlying sediments by the 1953 winter storms (Rudkin 1975)

2.6.3 Waterfront Archaeology

Waterfront archaeology refers to buildings or structures which front onto the river or shoreline, particularly within towns and ports. Such sites form nodal points in transitions across maritime and terrestrial landscapes (Parker 2001), and as such are vital to the understanding of the changing patterns of internal and overseas trade and interaction. Waterfront archaeology is important in charting not only where activity and settlement was focussed but also in helping to answer questions about the development of coastal and river systems through time, as they help chart the shape and position of watercourses, as well as their navigability. Importantly historic waterfronts can also help to answer questions about RSL and tidal range, as they form datum points that can be dated to a high degree of accuracy.

As with coastal defences, ports and harbours occupy strategic points in the landscape, exploiting natural harbours, tides and topography, and as such have long periods of occupation and reuse. Consequently there are very few examples of listed quays or wharves, as they are rapidly adapted to changes in shipping and ship technology (Fulford *et al.* 1997). There are a large number of factors that can be seen to cause changes in historic waterfronts over time. These have been loosely summarised by Milne (1999) as:

1. Natural factors - sea or river level change, coastal erosion, silting up of the harbour.
2. Artificial factors - encroachment, cutting new canals, bridge-building.
3. Economic and political factors - dynamics of market economy, increased specialisation of production, change from beach market to merchant port, changes related to imposition of Danish or Norman rule etc.
4. Nautical factors - change in ship size, change in more specialised craft.
5. Combination of the above.

However, the importance of natural factors can be argued to be the most important of these, particularly in pre-industrial society when harbours could not be dredged (Milne 1999). The relocation of the port of Dover in the 15th century AD (Philp 1981) and the abandonment of the port of Sandwich in the 16th century AD (Milne 1981) were both caused by excessive silting of their harbours, rendering them inaccessible and thereby defunct. Both changes to sedimentation and shipbuilding technology can also account for the movement of waterfronts, with encroachment of land to create deeper moorings slowly moving the interface. At long-established ports such as London, Dublin or Hull this has led to the river being pushed up to 100m from its original course (Hobley 1981).

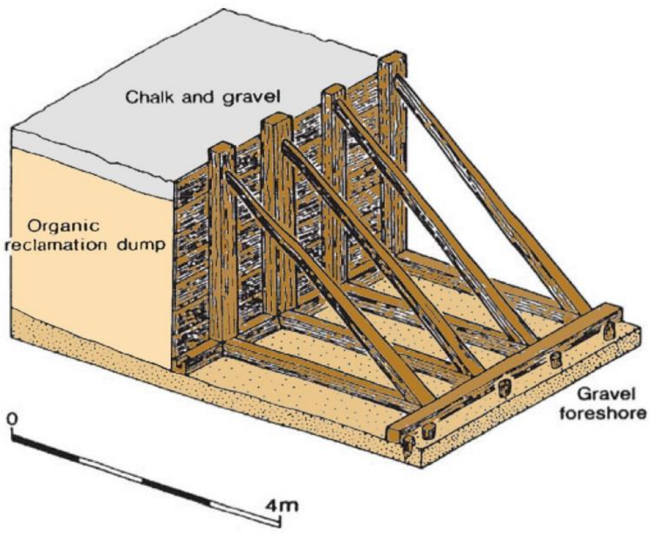

Figure 13 - A schematic reconstruction of a 13th century revetment revealed during excavations at Swan Lane, London (Good et al. 1988)

Waterfront archaeology has a fixed relationship with RSL and local tidal range, and provides accurate datum points as they can be used to correlate both the HAT and mean high water spring (MHWS) mark.

As focal points for trade and transport of goods, waterfronts provide a valuable repository for archaeological artefacts, as well as providing optimum conditions for their preservation.

The phenomenon of encroachment, by which revetment was used to extend and deepen the waterfront (**Error! Reference source not found.**), has likewise facilitated the preservation of archaeological material, both by encapsulating earlier archaeological material underneath made ground, and through the nature of the structures themselves.

The timber technology used to construct such revetment frequently contains portions of reused material, most often from broken up ships or buildings (Milne 1999). Such material is an incredibly important tool in reconstructing timber technology of under-represented periods (Brigham 1992) and, where it exists in great enough quantity, can help to fill in gaps in the chronology of building techniques, and help to construct a wider picture of the historic townscape.

2.6.4 Tide Mills

A tide mill (also referred to as a tidal mill, sea mill or salt mill) is a form of watermill that relies partly or wholly on tidal action to create power. The predominant use of the technology was for the grinding of grain, however the rotary power produced by tide mills has been harnessed for a wide range of uses, including ice crushing, grinding salt and bone meal, iron founding and the generation of hydro-electric power (Charlier *et al.* 2004). Tide mills function by enclosing seawater within a pool or reservoir at high tide, then releasing it through a sluice to drive a wheel once the tide has fallen to a sufficient level to generate the force needed (**Error! Reference source not found.**). Although principally driven by tidal action, tide mills require a tidal range of only two or three metres to create the necessary head water to drive the wheel. Within the post-medieval period adaptations to the technology allowed wheels to be driven both on the flood and ebb tides (Lucas 2006). Unlike other forms of watermill, tide mills are limited in their operation by the rise and fall of the tide, varying their functionality depending on the tidal regime. A spring tide typically allows operation of a mill for up to six hours, whilst the mill is not usable during neap tides or when the wind is against the tide (Wailes and Gardner 1938). On an average tide, the mill is usable from about three hours after high tide, when the tide has fallen sufficiently to create the headwater, meaning that the operation of a tide mill frequently required anti-social working hours.

Tide mills are mainly located on indented coastlines both to allow the construction of a suitable mill pond, and in order to provide shelter against storm damage (Lucas 2006). Often they are situated on a tidal creek or where a river enters an estuary, allowing an additional freshwater source to provide the basis of the water supply (Wailes and Gardner 1938). The positioning of mills within the freshwater/saltwater interface, and the frequent use of more than one water source, has led to issues of identification with early mills, with some sites proposed as tide mills that may have been driven by freshwater sources. Knowledge of the exact position of these sites within their contemporary tidal regime is therefore of the utmost importance in identifying their exact nature.

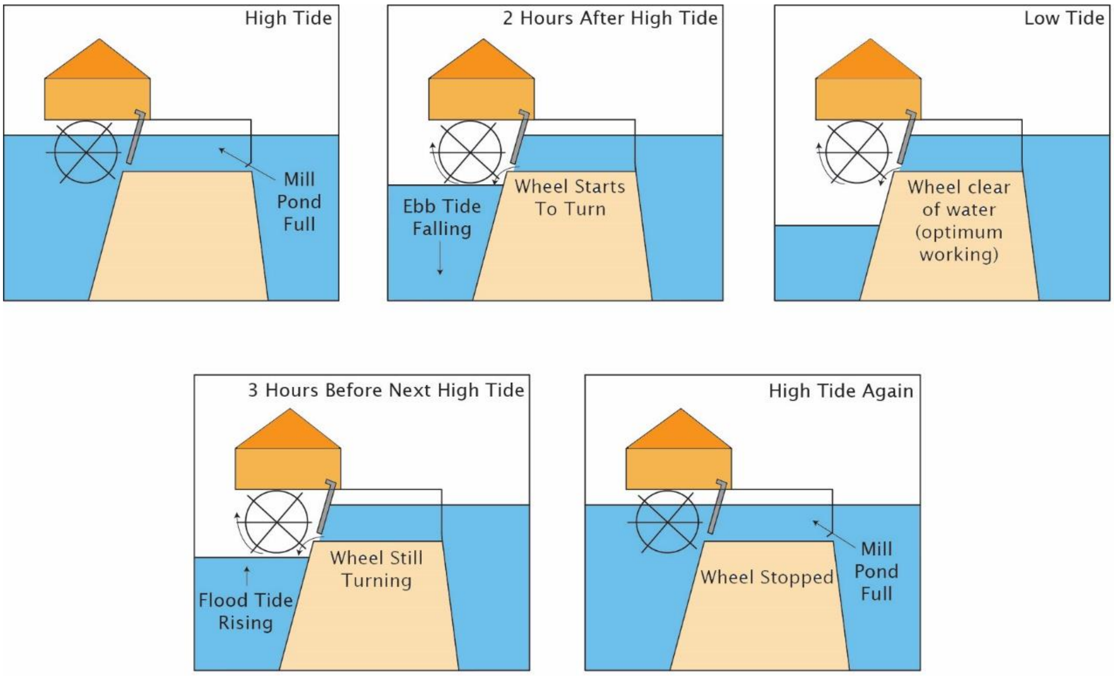

Figure 14 - Diagram showing the various stages of the process by which a tide mill functions (after Charlier and Menanteau 1997).

Along with the necessary topographical requirements, the placement of tide mills has a strong social context. Medieval documents frequently refer to tide mills blocking navigation or entry to harbours, and the placement of mills above the tidal reach on rivers in medieval cities such as Dublin and Cork (Rynne 2000) may have been to prevent the blocking of the ports. The purported tide mill at Dover, mentioned in the Domesday Book, may have been removed due to the water turbulence it created within the medieval port (Lucas 2006).

Ironically, the existence of large ports also accounts for the presence of some tide mills, within England, the concentration of mills on the south coast, rather than on more topographically appropriate areas such as the North Sea coast or Severn Estuary, reflects the importance of market forces in supply of the naval ports (Charlier *et al.* 2004) as well as for the wider population and for the export market (Charlier and Menanteau 1997).

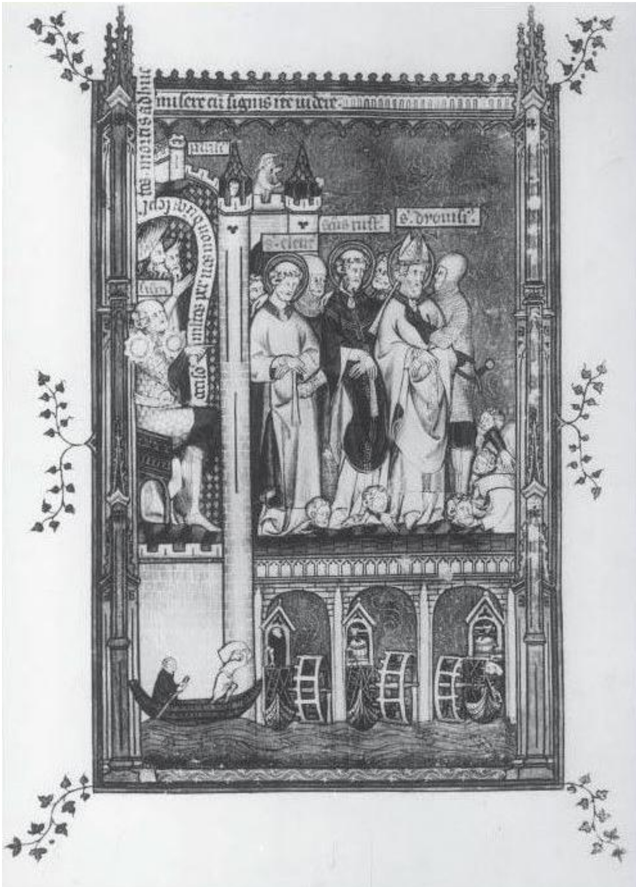

Figure 15 – Illustration from a French manuscript of 1317 showing watermills below the arches of the Grand Pont, Paris (reproduced in Reynolds 2006)

The position of tide mills, and their limited hours of operation, meant that they were often combined with other forms of industry, with the mill pool used as a saltern or for the trapping and storing of fish. Although tide mills are most often permanent structures in their own right, wheels driven by tidal action were attached to bridges on the Thames from the 17th-19th centuries (Wailes and Gardner 1938), similar to those found on non-tidal stretches of the Seine (Reynolds 2006; see Figure 15), and an inter-island mill existed at Penvénon, Cotes d'Armour (Charlier *et al.* 2004). Numerous medieval documents also describe wheels positioned on boats moored in the middle of tidal estuaries and rivers.

With the exception of a 10th century A.D. document noting a tide mill at Basra in Iraq (McErlean and Crothers 2007), tidal milling is predominantly a feature of the north-western European Atlantic littoral zone, until the 17th century when European settlers introduced the technology to North America, and later in the 19th century when the technology was transported to Australia

(Charlier *et al.* 2004). However, there is some documentary evidence to support the presence of tidal milling within the Adriatic from the 11th century onwards (Lucas 2006), while the remains of a suggested Roman tide mill has been reported on the River Fleet in London (Spain 2002). The first firm evidence of the technology comes from archaeological sites in Ireland, with early 7th century A.D. sites at Killoteran, Co. Waterford (c.600 A.D.) (Rynne 2000), Nendrum, Co. Down (619 A.D.) (McErlean and Crothers 2007) and Little Island, Co. Cork (630 A.D.) (Wikander 2000). The comparative density of this technology within Ireland is reflected in the 7th century texts *Di chetharṡlicht Athgabála* (Of The Four Divisions of Distraint) and *Coibnes Uisci Thairidne* (The Kinship of Conducted Water), the earliest known documents dealing with milling, mill construction, mill-races and milling rights (McErlean and Crothers 2007). In England, a similar style of mill has been found in the Ebbsfleet valley near Northfleet in Kent, with a construction date of AD 691-2, manipulating a natural tidal backwater of the river to form the basis of a millpond (Hardy *et al.* 2011; Figure 16).

Figure 16 – The remains of the late 7th century AD tidal mill excavated from the alluvium at Northfleet in Kent (Hardy *et al.* 2011). Note the penstocks to the right of the picture.

Documentary evidence from England dating to 949 A.D. mentions a *mylenfleotes mypan* (roughly translated as mill on an estuary or tidal creek) at Reculver, Kent (Rahtz and Bullough 1977), and a potential tide mill is mentioned in the Domesday Book at Dover, Kent (Spain 2002). As with a range of intertidal activities, early medieval and medieval tide mills involved a significant investment in resources, and so were constructed and operated by secular and monastic landowners, with rights to their construction and operation given as grants by the crown. Early sites at Nendrum, Co. Down and Little Island, Co. Cork were both monastic, with later 12th and

13th century tidal mill sites in England operated by the Knights Templar and Hospitallers. The importance of such structures to monastic communities was partly driven by practical concerns, i.e. the need for them to produce grain for the monastic community, and partly by theological necessity. The Rule of St Benedict which governed many later religious houses emphasised the need for monastic houses to remain self-sufficient (Benedict 1907). Sites such as Nendrum are known to have housed around 400 monks, so the use of tidal milling was of tremendous importance.

By the 12th and 13th centuries A.D. there are numerous documentary references to tidal milling sites throughout England, very often mentioned in relation to their damage or destruction by storm. From the late 13th century through to the early post-medieval period, there were dramatic episodes of climatic change, which led to numerous mills being abandoned due to flooding and erosion (Fulford *et al.* 1997). This frequent damage, along with the abandonment of tidal mills due to more mundane changes in the intertidal environment such as sedimentation and infilling of millpond tidal backwaters (Charlier and Menanteau 1997), led to the perception of tidal mills as an outmoded form of technology, and their abandonment in favour of windmills and riparian watermills (Holt 2000).

Despite the change to more reliable forms of power, tide mills continued in use into the post-medieval period. Industrial change led to their adaptation to metal working, with tide mills powering iron founding in Portsmouth, Hampshire and Bidstow, Cheshire, and copper smelting at Hugh Mill in Cornwall (Charlier and Menanteau 1997). The conversion of the Portsmouth mill to power the arsenal pumps in the late 17th and early 18th century was symptomatic of a wider move across Europe in the 18th century, with sites in El Ferrol (Galicia, Spain) and Basse-Indre (Loire-Atlantique, France) also using tidal milling to power arms manufacture (Charlier and Menanteau 1997).

Tide mills remained popular until the late 19th century, with a few still in operation into the 20thcentury, with an attempt being made to convert the technology to produce hydro-electric power in France in 1960s (Charlier *et al.* 2004).

2.6.5 Oyster fishing

Very little work has been done on the history of the oyster industry in Britain, and in particular the archaeology associated with growing or storing oysters. Whilst Britain's oysters found favour as early as the Roman period (see quote at beginning of Chapter 6), little is known of their manner of production. Artificial oyster beds are known from the 1st century BC in southern Italy, but there is no evidence that the Romans introduced this system to Britain, and it is entirely possible that Roman Britain relied on natural oyster beds until a relatively late period. A number of oyster production sites such as Emsworth in Hampshire and Mersea in Essex are known from documentary sources to have been in existence since the 14th century AD, but again it is difficult to assess the exact nature of these sites. Part of the problem with the identification of early oyster farming from documentary sources is that there is a great deal of confusion in the use of terminology. The term 'beds' can refer to deliberate oyster cultivation, or the areas of sea floor from which the oysters are dredged, or be used as a legal term to define specific fishing rights for areas of the sea floor. Newell (2011) has proposed terminology for referring to oyster fishing in an attempt to reduce such confusion.

1. An oyster *bed* is a naturally occurring area where oysters grow without assistance.
2. A *lay* is an area of seabed that is tended and managed by fishermen but looks like a natural environment.
3. A *pond*, *pen* or *pit* is an artificial hole dug in the foreshore, or seabed, for oysters to be stored until needed for market.

Oyster pits were used for both the seeding and storage of oysters or other shellfish. Most often these are formed of timber lined pits with a sandy layer at the base designed to retain a level of seawater at low tide. These pits were used to store live oysters after dredging, either to seed them for replacement in offshore oyster beds or farms, or to keep them alive and fresh prior to sorting and shipping. It is assumed that the bulk of the surviving structures, such as those at Emsworth, Hampshire or Mersea and Paglesham, Essex, date to the 19th and early 20th centuries, although little work has been done to date them using scientific methods. Archaeological evidence for oysters tends to take the form of shells and shell middens (e.g. Horse and Winder 1991). More recently isotopic analysis has been used to infer shellfish consumption, but this does not specify species or the means by which the shellfish were fished or farmed.

2.7 Intertidal Fishing Structures

Intertidal fishing structures represent a wide variety of technologies that use the variance in level between high and low waters to trap fish. These range from the classic 'V-shaped' weirs to baskets traps such as putchers and putts to the Irish 'head weirs' used to catch salmon. It is important to remember that they represent only a small percentage of the fishing methods employed around the coast. Fishing with lines, spears and nets in the inshore, offshore and deep-sea zones are often occurring at the same time, and in many cases are less visible in the archaeological record. Documentary sources that refer to fishing often add a great deal of confusion, with terminology being vague, or legal rather than physical (such as 'fishery'). Very few historical sources contain information on how such structures actually function, and consequently there is a lot of assumption about their usage. In addition, colloquialisms such as 'kiddle', 'yair' and 'cored' are frequently taken to refer to specific forms of structure rather than being general terms. In many cases intertidal and waterfront structures that are not directly fishing related have a secondary function as a site for procuring fish. The large tidal pools for salt works and tidal mills, river locks and weirs are all used as points at which to trap fish, usually on a small scale by means of baskets. Documentary sources from the 14th century through to the 20th century show basket traps attached to mill leats (see Figure 17 below), weirs, and locks. This exploitation indicates an opportunistic, multilateral approach to the procurement of fish and shellfish.

Figure 17 - Illumination from the 14th century AD Luttrell Psalter (© British Library). Eel baskets can be seen in the mill leat to the right of the image.

Similar 'pits' to those used for oysters are known for the storage of live fish prior to processing or transport. These appear on tithe maps and first edition OS maps at sites in Essex and Hampshire. As storage sites, they appear to have had a direct association with production sites, such as salterns and fish-traps (Currie 2000).

2.7.1 Importance and Use of Fish

Although primarily a foodstuff, fish provide a wealth of other materials that were of use in pre-industrial societies. The skin and scales of fish are still used as a clarifier for coffee and beer (Unger 2004); the skins can be tanned like leather to produce shoes, sackcloth and even clothing, whilst the particularly tough skins of eels were made into thongs, often used to tie down eel baskets (Berg 1984). The bones and skin of fish could be boiled down to create *isinglass*, or fish glue, known to have been in use in Egypt as early as the 2nd century BC (Petukhova 2000). In the medieval period fish glue was used both as an adhesive and as a preparatory material for vellum parchment and for mending of manuscripts, and mixed with pigment for wall painting and manuscript illumination (Petukhova 2000). This has implications for the lack of fish bones and consumption of fish at monastic sites. Other more obscure uses have also been noted. Excavations on the site of a 13th century chapel in Northumberland produced two rosaries made from the larger bones of cod and ling (Stallibrass 2005). In Orkney, during the post-medieval period, coalfish being hung to dry or smoke also provided illumination, the carcasses glowing with a phosphorescent light as they dried out (Fearnley-Whittingstall *et al.* 2007) and decayed fish skins were used for illumination in European coal mines prior to the invention of the safety lamp (Smiles 1862).

2.8 A History of Intertidal Fishing Structures in the British Isles

The following presents a brief chronological overview of known intertidal fishing structures in the British Isles.

2.8.1 Mesolithic

Within Mesolithic Britain, structures associated with fishing are notable in their absence, especially in the context of other northwest European sites. Lack of evidence for Mesolithic fishing structures within the British Isles has been variously attributed to inundation, the non-preservation of organic materials used in their construction or to a general lack of excavation on wetland sites of the period (McQuade and O'Donnell 2007). One of the main reasons for the lack of evidence is the loss of Mesolithic coastline due to sea level rise, the remainder of existing coastline above water representing only a fraction of what was there, with the exception of northern Britain where isostatic uplift has outstripped eustatic rise in sea level (Cunliffe 2001). Along with an absence of fishing sites, there is a lack of evidence for any fishing gear, harpoons have been found in Scotland that could have been for fishing, but it is much more likely that they were used seal hunting (Smart 2000). A range of bone points and a harpoon have been recovered from the inland site of Star Carr (Robson *et al.* 2016), but the paucity of evidence for fish remains within the Flixton palaeo-lake means that it is not clear if these artefacts were associated with fishing or some other form of wetland hunting such as wildfowling.

The nature of Mesolithic fishing within Britain therefore has to be reconstructed from more indirect evidence. Analysis of fish remains from two sites in Britain points towards an active pursuit of fish, and has implications for the technology used in their capture, despite a lack of artefactual evidence. The fish bone evidence recovered from Goldcliff in the Severn Estuary suggests that the predominant species being pursued was eel – *Anguilla anguilla* (Ingrem 2007). The frequency of eel bones and their small size suggest that the eels had been caught using traps positioned in shallow water. Analysis of the growth rings suggests fishing took place through the autumn, which would be consistent with the life cycle of the eel, which migrates downstream to the sea in the autumn heading for the breeding grounds in the Sargasso Sea. At this point the eel is not only at its largest (and arguably its tastiest) but, with the use of fixed baskets, it is at its most catchable. The site of Oronsay in the Inner Hebrides has also yielded skeletal evidence which points to the nature of Mesolithic fishing. Remains of several species of fish were found within Mesolithic shell middens around the island, with the major focus being on saithe - *Pollachius virens* (also known as coalfish or coley). The analysis of the fish otoliths showed evidence of exploitation of saithe at several clearly defined seasons of the year, suggesting fishing over most of the annual cycle (Mellars and Wilkinson 1980). Different shell middens provided different seasonal dates, suggesting either one population moving around the coastal landscape, or a population from the mainland camping on different parts of the island at different times of year (Cunliffe 2001). In either case, a deliberate targeting of species appears to be apparent. As saithe are usually found offshore in rocky areas, the suggestion has been put forward that boats were used to pursue the fish (Steane and Foreman 1991). However, in northern England and Scotland saithe are known to congregate much closer to the coast and can be caught with rod and line from rocks (Fearnley-Whittingstall *et al.* 2007).

Potentially, shell middens could be seen as evidence for bait rather than food for human consumption (Smart 2000). Evidence for the use of shellfish as bait and the subsequent production of shell middens is known from both historic and ethnographic sources (Horse and Winder 1991: Fenton 1984) and would be indicative of the use of fixed fishing traps or hooks. However, neither traps nor hooks have yet been found within British Mesolithic contexts.

Smart (2003) has argued that in the absence of fish traps a determination of actual fishing is difficult, as dependent on context, bones from sites need not imply fishing or fish consumption. However, the contextual evidence from surrounding European countries may both defend the presence of fixed fishing structures in Britain during this period, and shed light on the absence of evidence within the archaeological record. In Ireland, fish baskets have been found in Dublin, within the palaeoenvironment of the River Liffey. These have produced the earliest securely dated fish traps in the UK or Ireland dating to the Late Mesolithic between cal BC 6054-5911 and cal BC 5871-5723 (McQuade and O'Donnell 2007). More recently a similar site has revealed further Mesolithic fish baskets within the Dublin quay area (Ryan 2013; **Error! Reference source not found.**).

Both sets of traps were found in advance of construction works in the Dublin quays, the first at a depth of five metres below Ordnance Datum. Two potential examples of Mesolithic fish weirs also exist in Northern Ireland, consisting of an arced arrangement of stones and wood on the Late Mesolithic site at Newferry, Co. Antrim and an undated wattle fish weir found beneath deposits near Toomebridge, Co. Derry (McQuade and O'Donnell 2007). In both cases neither has been directly dated. Further, indirect, evidence exists at Mount Sandel on the Bann Estuary, where the fish bones from a large number of estuarine species within a 7th millennium BC context has provided the earliest evidence of fish exploitation in Ireland (McErlean *et al.* 2002).

Figure 18 - Remains of a Mesolithic fish basket found below the reclaimed waterfront during the Victoria Quay excavations in Dublin. Scale 50cm (Ryan 2013)

Evidence from the French site of Noyen-sur-Seine has yielded similar baskets to those found within the Liffey, in this case within a riverine rather than estuarine context. Associated fish bones from the site show that eel were pursued during the periods that the baskets were in use. Fishing appears to have been a year round activity, with a focus during the summer months (Mordant and Mordant 1992). By far the best examples of Mesolithic fishing structures have come from Denmark, where both basket traps and weirs of wicker screens were used during the Mesolithic (Smart 2003). Sites at Bjørnsholm in northern Jutland (cal BC 5985-5709 to cal BC 5006-4701) and Halsskov Island in the Storebælt have produced fragmentary remains of fish weirs (Bødker-Enghoff 1991; Pedersen 1997). Associated fishbone evidence has shown the assemblage to be dominated by eels caught with baskets, eel bones at Bjørnsholm accounting for 56% of identified bones. The site was optimally placed for this sort of fishing, lying at the mouth of the freshwater streams discharging into the Bjørnsholm Fjord (Bødker-Enghoff 1991). Again, as at Noyen-sur-Seine, the seasonality of the fish suggests that fishing was a predominantly summer pastime.

The context of European Mesolithic sites show that evidence exists in countries to the west, east and south of Britain for the use of fixed fishing structures and baskets during the Mesolithic period. This, taken in conjunction with the more indirect fish bone evidence, makes it highly unlikely that they were not also present within Britain. Questions should then be raised about their apparent absence from the archaeological record. Firstly, given the coastal change that has occurred since the Mesolithic are fixed fishing structures more likely to exist below sea level? The Danish site at Halsskov Island was found using a 'fishing site' model designed to predict the potential for submerged Mesolithic coastal settlements (Pedersen 1997). Ongoing work at Wootton-Quarr on the Isle of Wight have shown the potential for this sort of evidence to be recovered in submerged contexts within the British Isles (Tomalin *et al.* 2012). Secondly, is there a greater potential for fishing structures to exist in terrestrial contexts at depth? Those found in Ireland were part of a Mesolithic land surface five metres below current Ordnance Datum, and were only uncovered during deep excavations (McQuade and O'Donnell 2007). Comparison can be made with the Boston Back Bay weirs in Massachusetts, which were found at a depth of 30 feet (9.14m) below modern street level (Johnson 1949). In both cases the structures had been buried by a process of reclamation and infilling of estuarine basins in more recent periods. The possibility exists that sites could survive in similar contexts in mainland Britain. From the available evidence it can be concluded that Mesolithic fishing in Britain took a similar form to that within NW Europe. The potential exists for better evidence to be exposed in the future within the intertidal zone or in areas of reclaimed land. Further, underwater sites such as that at Bouldner Cliff (Momber *et al.* 2011) show the high potential of underwater sites to reveal submerged structures similar to those found in Denmark.

2.8.2 Neolithic

The current model for the transition from the Mesolithic to the Neolithic is marked by a vast reduction in the reliance on fish and shellfish as a foodstuff with the exploitation of marine resources being secondary, and inversely proportionate, to the availability of resources on dry land (Clark 1952). The question of reliance on terrestrial vs. marine food sources is one that has continued into current archaeological debate with the introduction of new archaeological evidence and scientific techniques. In particular, the use of isotopic analysis of human remains has raised fresh debate about the shift in nutritional resources associated with the transition from Mesolithic to Neolithic (Milner *et al.* 2004; Richards and Schulting 2006; Milner *et al.*

2006). Whilst debate now focuses over the proportion of marine foodstuffs in the diet, there is general consensus that fishing continued into this period, albeit as a more peripheral food-gathering activity, or as a fall-back food (Richards and Schulting 2006; Bødker-Enghoff 1991).

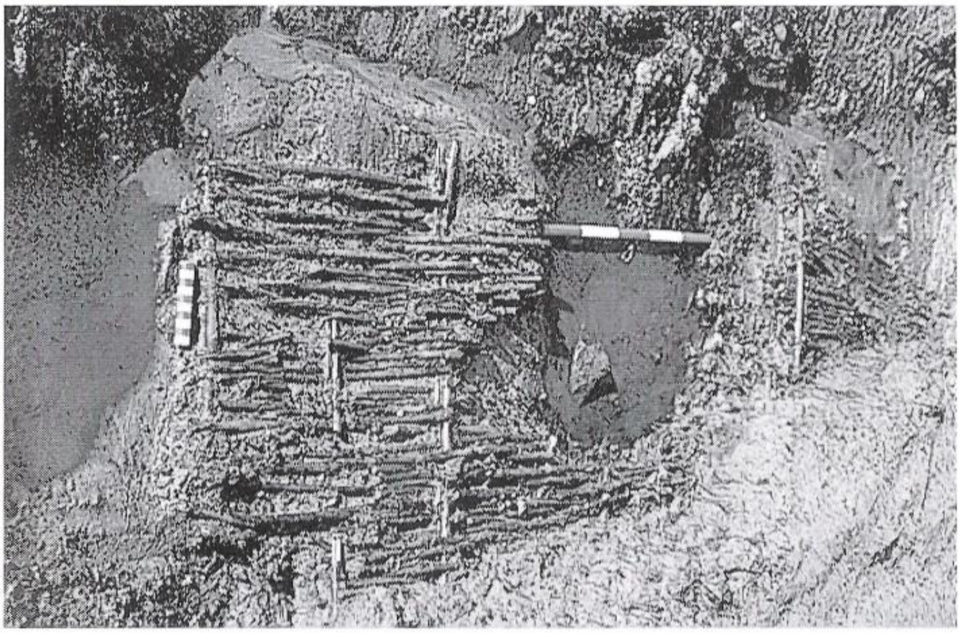

Figure 19 – A wattle panel discovered within the peat beds near the submerged forest at Seaton Carew, Co. Durham. The panel was dated to the Neolithic period through its stratigraphic relationship to the peat beds and presumed to be a portion from a fishing structure. Scales: 10cm and 25cm (Daniels 2000)

Within Britain, very little evidence exists for the continuation of fixed fishing structures into this period. A lone post and wattle panel recovered from the intertidal zone at Seaton Carew, Co. Durham was dated by its stratigraphic position to the Neolithic and has been proposed as a panel from a fishweir (Daniels 2000; Figure 19), although the fragmentary nature of the evidence allows for its interpretation as a trackway or indeed any number of post and wattle built structures. More recent work at Wootton-Quarr on the Isle of Wight has produced possible fishweirs and stakes for smaller fish traps (Tomalin *et al.* 2012), although no full excavation of the structures took place. A much more convincing structure was uncovered in a palaeochannel at Hemington in Leicestershire, consisting of a post and wattle structure dated to cal BC 5642-5485 (Clay and Salisbury 1990), although this date has subsequently been disputed.

The relative lack of evidence for fixed fishing structures from Neolithic contexts in Britain has given rise to the suggestion of misidentification of the archaeological evidence. Smart (Smart 2003) has asserted that some of the "tracks" found in British wetland sites could actually be remains of hurdles from wicker weirs, and has speculated that a Neolithic 'wicker fence' in

England would be interpreted as being a trackway whilst the same structure in Denmark would be interpreted as a fish weir.

2.8.3 Bronze Age

A line of stakes and wattle was found at Newferry on the lower Bann, Northern Ireland, and dated in relation to its geology to at least 1000 B.C. (Mitchel 1965). More recent excavations at Must Farm, Cambridgeshire have uncovered a fish weir dated to the Later Bronze Age (cal BC 1300-800) (Figure 20). The weir was built offsite as a series of long hurdles that were then attached to large posts. Analysis of the structure has indicated that the panels were replaced at least twice, showing continued usage of the site. A total of 18 basket traps from the same period (cal BC 1250-800) were also located within the same palaeochannel, and have been interpreted as eel traps, based on their close-weave and shape. Although the sites are not numerous, the complexity of the structures suggests that the technology was substantially advanced during this period. As with Mesolithic weirs, the Bronze Age examples were both found at depth, in the case of Must Farm between -1.8 to -2.8m O.D., allowing for the possibility of similar sites to exist within wetland or intertidal contexts. Within the Bronze Age there is strong evidence for salt making on the east coast of England, the extent of this activity could be associated with fish processing.

Figure 20 – The Late Bronze Age weir uncovered during excavations of a palaeochannel at Must Farm, Cambridgeshire in 2010 (Robinson *et al.* 2015)

2.8.4 Iron Age

From all available archaeological evidence, including fish bone assemblages from excavation sites, there appears to be very little evidence of fish consumption in Iron Age Britain (Dobney 2001). No fixed fishing structures are known from the period, however in Denmark there is a technological shift to fishing with nets, sinkers and weights during this period (Bødker-Enghoff 1999), so the lack of fixed fishing structures may not indicate an absence of fishing practice. Sites that have yielded evidence for fish consumption appear to be the exception rather than the rule, and no clear procurement strategy for fish can be ascertained for this period in Britain.

2.8.5 Roman period

The Iron Age avoidance of fish, whether cultural or otherwise, appears to have continued into the Romano-British period, which is surprising given the large degree of fish consumption within the Roman Mediterranean (Dobney 2001). However, this was most likely due to the absence of a fishing tradition amongst the native population, rather than an abandonment of Roman tastes (Dobney 2001). There is some evidence to suggest that fish was an elite foodstuff, the Romans are credited with introducing carp (both as an ornamental pond fish and an elite food item (Bødker-Enghoff 2000), and edicts from the Emperor Diocletian show river fish costing as much as meat, whilst sea fish was twice as expensive (Larje 1995). This has been supported by stable-isotope analysis carried out on both elite and poor from the 4th century site at Poundbury. The results indicated consumption of seafood amongst the elite but not amongst the poor (Cool 2006).

The evidence for fish consumption in Roman Britain has been hampered by a lack of systematic sampling for fish bone evidence at excavation sites, meaning that there is a lack of knowledge about what species may have been consumed (Cool 2006). The sites that have produced bone evidence are substantially skewed towards urban and military sites (Dobney 2001). Further complications are added by the large-scale consumption of *garum* or fish sauce, made by layering oily fish, herbs and flavourings and then fermenting the resulting mix in the sun. The large amounts of fish bones found in latrine deposits at urban and military sites may be indicative of the consumption of fish sauce, rather than fish itself (Cool 2006).

The potential evidence for imported fish sauce found at Skeleton Green, East Hertfordshire within the pre- Roman Iron Age marks the beginnings of a large-scale import of garum and other sauces from the Iberian Peninsula (Dobney and Ervynck 2007). The Roman taste for fish sauce appears to have encouraged the development of a home grown industry, with potential fish sauce factories occurring in London (Bateman and Locker 1982), Lincoln (Dobney *et al.* 1996) and York (Wenham *et al.* 1987).

The Roman period shows a large increase in the consumption of oysters, however these appear to have been naturally abundant, rather than being farmed (Cool 2006). Of the fish bones which have been recovered from Romano-British sites, most represent species which would have been easily caught in rivers or inshore (Dobney 2001), and even the oily fish used to produce fish sauce could have been caught in the inshore waters, or from shore using seine nets. The Roman approach appears to have been a casual exploitation of what was at hand (Cool 2006), with little serious investment in large scale fishing structures. This is in keeping with sites from the Mediterranean, where most species appear to have been caught from inshore to mid-water most likely using lines and nets (Larje 1995). No evidence for more permanent constructions are known anywhere in the Roman period, stakes dating to the Roman period have been found in the intertidal, however as yet none have been identified as fishing structures.

2.8.6 Early Medieval

As with most aspects of Anglo-Saxon studies, an overreliance on documentary sources has led confusion over the nature of Anglo-Saxon fishing. References in Bede (Sherley-Price 2003) and the Life of St. Wilfrid (Stephanus 1985) to early Christian missionaries teaching local tribes to fish have often been taken at face value, rather than as allegorical references to their conversion to Christianity. A taste for fish had clearly developed during this period, attested to by the large amounts of fish bones at sites such as West Stow (Banham 2004), and early Saxon fishing structures have recently been discovered on the foreshore of the River Thames, dating from between the 5th to 7th centuries A.D. (Cowie and Blackmore 2008). Between 650 and 850 AD there was a general increase in agricultural activity in Britain, which is matched by the greater exploitation of marine and riverine resources (Astill and Langdon 1997). Weirs also dominated river courses during this period, both in large estuaries such as Blackwater, where weirs of 7th to 9th century date have been found (Hall and Clarke 2000), to inland rivers such as the Trent, were weirs have been found at Colwick (Losco-Bradley and Salisbury 1988). These weirs date to the same period as the sites of Fishergate and Coppergate in York, whose fish bone assemblages suggest that similar fish procurement strategies from nearby rivers (Bødker-Enghoff 2000). Later Saxon documents provide a wealth of information on the use of fixed fishing structures during this period, the earliest document referring to a site at Aust in c.690 A.D (Rippon 1997). On the opposite bank of the Severn, at Tidenham, a 10th century charter lists 104 fish weirs in the Severn and Wye belonging to Bath Abbey (Bond 1988). This is matched by the archaeological evidence, with structures identified in the Severn Estuary RCZAS in the parish of Tidenham dated by radiocarbon to between the 8th and 10th centuries A.D. (Chadwick and Catchpole 2010). Aelfric's Colloquy, a 10th century document used to teach Latin, mentions some of the specific technology used by fishermen, and refers to nets, spears and wicker baskets, as well as the practice of hunting whales in boats, but does not mention the use of weirs. 'Sea-hedges' or foreshore weirs are, however, mentioned in the laws of Hywel Dda in the early 10th century (Bond 1988), showing their importance around the coast of Wales. The resource was important enough to have shaped the wider countryside, with the layout of parishes in coastal counties maximising access to the foreshore (Serjeantson and Woolgar 2006).

2.8.7 Medieval

The Medieval period saw an exponential growth in the evidence for the exploitation of marine and riverine resources for the provision of fish. Partly, this growth is due to the vast increase in documentary sources from the 12th to 13th centuries onwards, and attributable to the growth of the bureaucratic system rather than to changes in fishing practices (Taylor 1988). However, the archaeological evidence substantiates a rapid expansion in fishing activities within this period, and a broadening of the methods employed to obtain fish. Bond (1988) has subdivided this expansion into seven major developments:

1. Development of sea fisheries from the coastal ports.
2. The construction of foreshore weirs or sea-hedges.
3. The collection of shellfish.
4. The definition of fishing rights in natural lakes and marshlands.
5. Inland fisheries and fish-weirs.
6. The setting of eel-traps in millstreams.
7. The construction of artificial ponds for the controlled storage and breeding of fish.

The chief reason for the large expansion in fish procurement and consumption was the rise in the scale and power of monastic influence in medieval Britain, and its resultant impact on society. The increased influence of the rule of St Benedict from the 10th century onwards, led to an increase in fasting, with fish being used as a substitute for meat (Serjeantson and Woolgar 2006). The avoidance of meat practiced and advocated by the church, and the subsequent demand for fish that it produced accounted for a significant part of the medieval economy. The church forbade meat consumption during the six week period of Lent, Fridays, and Saturdays and during religious festivals (Dyer 1988). In total fasting or 'fish days' accounted for about 40% of the year (Kowaleski 2010). The sheer volume of fish needed to sustain monasteries led to investment in a range of fishing practices, from investment in deep-sea fishing, through to freshwater fishponds within monastic precincts. Sea fish, however, appear to have been more important in the monastic diet than freshwater fish, and the use of both deep-sea fishing and foreshore weirs attest to this. Whilst fishweirs in freshwater rivers continue into this period, they were the source of frequent arguments over the obstruction of navigation (Rippon 1997), to such a degree that all weirs, with the exception of those on the coast, were ordered to be torn down in the Magna Carta (Summerson 2015). The granting of rights to construct weirs on the foreshore became an important social statement (Serjeantson and Woolgar 2006), and throughout the medieval period ownership of fish weirs and fishing rights was a common source of dispute between landowners, both religious and secular (Rippon 1997; Chauvin 1969). The mapping of Cistercian lands in the Severn Estuary by Bond (1988; see **Error! Reference source not found.**) shows the extent to which the coast was controlled by monastic landowners. Excavations on a range of inland monastic sites have shown the predominance of marine fish despite alternative freshwater sources such as rivers and lakes being located close by (Jones 1989). This may have been due to the prohibitively high costs of freshwater fish, which was in general only consumed by royalty or the aristocracy (Aston 1988).

The preferred method of storing fish for later consumption was to keep them alive. This lead to the construction of sea-ponds or fish pits, pools dug along the shore and refilled with tidal water, for the storage of marine fish subsequent to capture by weir or from boats (Currie 1988). There are obvious parallels between these structures and some forms of fish weir, and some may have acted as both, this blurring between traps, storage and pisciculture extends inland, where some fish ponds may in fact have been storage for marine fish (Hoffmann 2000).

The medieval period also saw the rise of deep sea fishing, with an increase in the consumption of cod and herring beginning in the 10th century (Serjeantson and Woolgar 2006), and becoming a major industry from the 12th century onwards (Bødker-Enghoff 2000). A number of factors influenced this development, a rise sea temperature in the 10th century moved herring shoals further north, whilst economically the demand for larger catches justified such excursions, whilst technological development in both boats and netting allowed the exploitation of the open sea. The larger and more predictable catches, along with developments in the preservation of fish were a significant factor in the demise of both fishponds and fixed fishing structures (Hoffmann 2000).

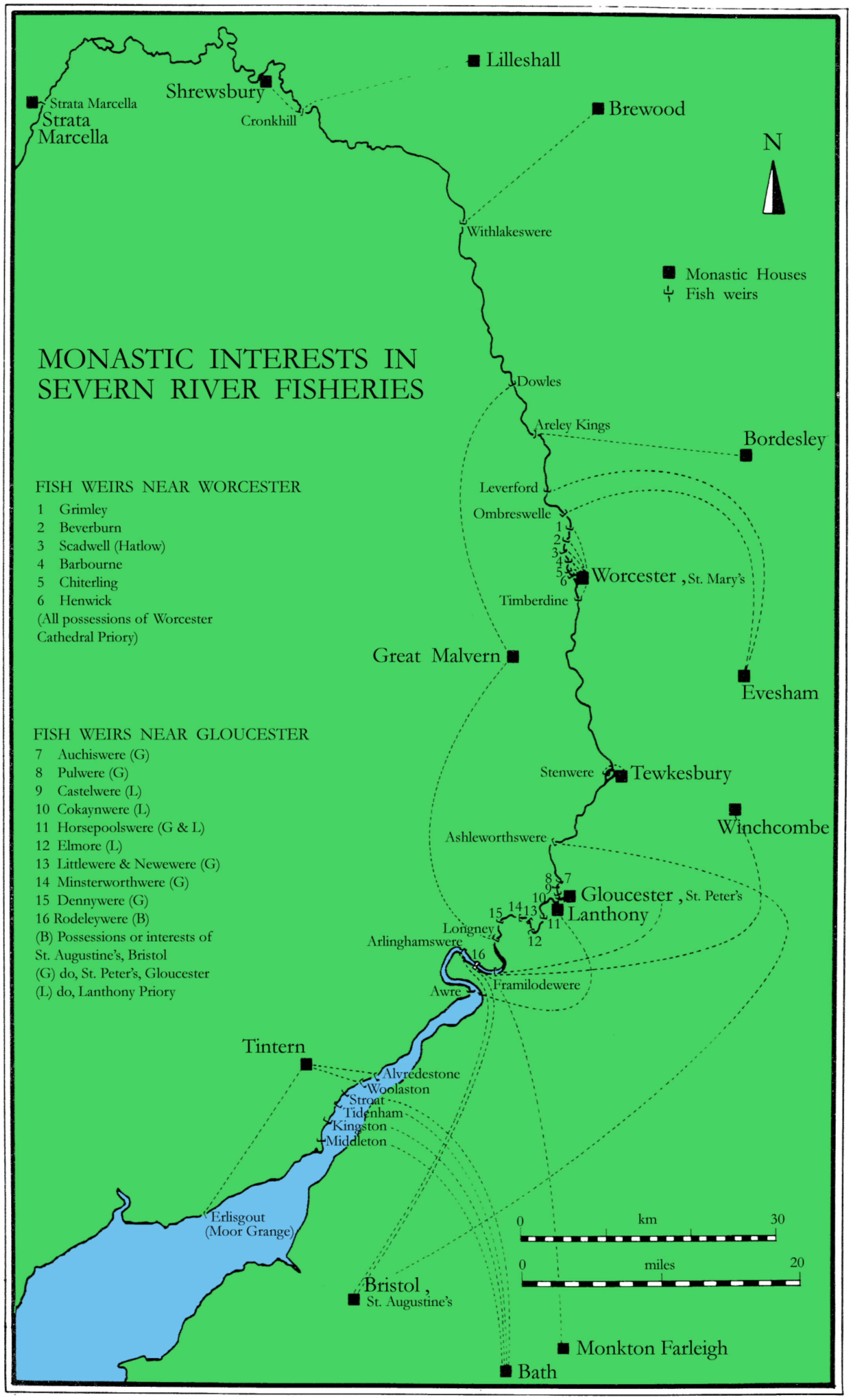

Figure 21 - Map showing the range of monastic control of river fisheries in the Severn Estuary (Bond 1988)

2.8.8 Post-medieval

The marked decline in the use of fixed fishing structures was also influenced by cultural factors. The Reformation, and its subsequent effect on the church, removed one of the main cultural reasons for the consumption of fish (Serjeantson and Woolgar 2006). However, this transition is slightly blurred, as fish days and Lenten fasts can be seen to carry long into the post-Reformation period (Hamilton-Dyer 1995), although this was is no small part due to economic measures imposed in the reign of Elizabeth I for the purpose of supporting the fishing industry in order to supply experienced sailors for the Navy. Substantial amounts of fish bones were recovered from the stores of the Mary Rose. With the exception of those destined for the captain's table, which were from conger eel and most likely caught in the intertidal zone, the vast majority were cod, reflecting the rise of deep sea fishing (Hamilton-Dyer 1995).

Figure 22 - Watercolour showing a 'Head weir' for catching salmon stretched across the River Shannon, Ireland (Anon, © National Gallery of Ireland). Note the platform in the centre of the structure used to hang nets to catch the fish, and the boat to the bottom left.

Fixed fishing structures did continue into the post-medieval period, but adapted to reflect changing tastes and economic concerns. The intertidal zone around Essex, Hampshire and Sussex became a focus for the oyster industry, as mentioned above (see Section 2.6.5 above), and involved the creation of square cut beds often lined with posts and wattle. Much research is still needed on the origins of this industry, but most surviving structures are taken to date to the post-medieval period. On the larger rivers of western Britain, the post-medieval period saw the development of large-scale salmon fisheries. This lead to the development of new forms of fishing technology, with the evolution of 'putchers' and later 'putts' in the Severn Estuary (see Section 2.10 below), and 'head weirs' in Ireland (**Error! Reference source not found.**). By the 20th century both these practices had declined significantly, in the case of the oyster industry due to pollution and in salmon fisheries due to a combination of canalisation and overfishing which heavily depleted stocks.

2.9 Fishing Landscapes – The Significance and Place of Intertidal Sites

Fishing related structures can be considered at three levels: artefacts, sites and landscapes. Artefacts related to the archaeology of fishing are represented both by moveable objects that may or may not be in their original context (e.g. hooks, net weights, fish baskets), and by the individual elements comprising fixed fishing structures. As archaeological artefacts, fish traps, or their individual components, can tell us much about the technological capabilities of the society in which they were constructed. Wooden fish traps, like all timber built structures, hold a record of the methods used in their construction. Marks left by tools on the exterior faces of the timber and 'jam curves', where the blade is stopped in the wood, can allow the reconstruction of the profile of the axe (Sands 1997). Analysis of these tool 'signatures' can not only reconstruct the manner of tool used but can identify patterns of phasing within the wider structure, provide a low-tech verification of scientific dating methods, and be used to make inferences about the number of people involved in the construction and their organisation (Sands 1997). Identification and analysis of such tool signatures and other technological practices (such as tying and weaving) across a site could help not merely to infer on the society creating the artefact and/or structure but also inform about the individual agents involved within its construction.

The identification of a process of active selection of materials used, rather than their selection based on availability, can tell us a lot about the society which exploited them (Brunning 2001). Analysis of the pollen record from the time of construction of the fishweirs at 500 Boylston Street, Boston showed a change in the type of timber selected for the construction of the weirs over a 1000 year period, from sassafras to alder (Kaplan *et al.* 1990). However, the continued presence of alder in the pollen record would imply that technological considerations rather than environmental ones drove the change in timber used in the construction.

Along with information on taxa that may be present within the local context, individual timber components can reveal aspects of local woodland management practices. Waterlogged wooden materials represent 'ecofacts' as much as they represent artefacts (Goodburn *et al.* 1998). Timber is a biological artefact and so can give a broader understanding of the ecological context of the society in which it was created. Timber built fishweirs and traps can be considered 'vernacular' structures in that they are designed using local conventions with an emphasis on function rather than form, and so are constructed almost exclusively from local materials (Brunskill 1970). This means that they can provide a broader ecological context to the landscape surrounding the structure, and can be used to complement and enhance pollen analysis (Brunning 2001).

The principal components of timber weirs are typically formed of large wooden elements shaped into stakes and used as posts. With the application of dendrochronology, substantial wooden elements such as these provide datable evidence for the structures, and have the potential to answer questions about their long-term use, as well as their replacement or repair.

The smaller components of timber weirs and traps are also useful sources of information and can be used to infer wider landscape management. Wattles are a good indicator of the practice of coppicing or pollarding of woodland. For example consistent sized, whole (rather than split) wattles suggest coppicing on a short rotation (Goodburn *et al.* 1998). Even within early periods, the type and wood used can inform on how societies were impacting on their local landscape (Brunning 2001)

As well as representing collections of both artefacts and ecofacts, some forms of fish trap can also be considered as a 'naturefact'. 'Naturefacts' are defined by Oswalt (1976) as 'unmodified natural objects that are used consistently by a group to obtain food or water'. The understanding of fish traps in the context of Oswalt's concept of naturefacts has important ethnographic implications for the cultural understanding of landscapes (Memmott *et al.* 2008). A consequence of this interpretation of fish trap sites is that it points to areas in which fishweirs may have developed a topographical layout organically, rather than as a planned imposition. Anecdotal and historic map evidence suggests that fish traps along the Severn Estuary were located to enhance or exploit natural pools or lagoons within the river channel. This augmentation of the natural resource is important in the understanding and interpretation of early sites and can help to explain the siting of traps. Bannerman and Jones (1999) classify these types of trap as 'Type 1. Natural features adopted as a trap' and 'Type 3. Modified natural feature trap', and cite examples of their occurrence from both Scotland and Wales. Memmott *et al.* (2008) cite this approach to trap construction as advantageous as it both maximises tidal flows by exploiting naturally occurring runoffs and reduces the amount of labour required in the construction by using existing topography.

As well as being part of the physical landscape, fish traps sit within a cultural landscape, and form a collection of related sites or artefacts that reflect wider patterns of marine exploitation. To understand this usage necessitates the application of 'landscape archaeology' which considers the interrelationship between archaeological sites and the spaces separating them (Chapman 2006). This approach to the study of fish trap sites is highly beneficial within early prehistoric periods as it can illumine our understanding of the seasonal use of resources and the movement of groups within the broader landscape. Within later historic periods, a landscape archaeology approach is still beneficial, as the creation and usage of fishing structures is within the context of a broader *economic* landscape, and can aid our understanding of the operation of monastic and secular estates and market forces at a national or even international level.

A landscape approach also draws attention to the blank spaces between sites. Within the historic period, increasing amounts are known about fish traps, and about markets and areas of consumption at the other end, but much less is known about the ways in which fish or shellfish were stored or processed prior to transport. Examples of fish processing and storage areas are known from Roman contexts at Lincoln (Dobney *et al.* 1996) and York (Wenham *et al.* 1987), from Medieval monastic sites at Whittlesea Mere, Cambridgeshire (Lucas 1998), Meare, Somerset (Jotischky 2011) and Byland Abbey, Yorkshire (Jecock *et al.* 2011) and from post-medieval sites in the Witham Valley (White 1988). However, the interpretations of all of these sites as fish processing structures are contentious, as comparative examples of each are practically unknown. A lot of research is needed to identify the methods used to store, process and transport fish within the archaeological record.

2.10 Understanding Structures

2.10.1 Intertidal Structures and theory

A number of challenges exist in the integration of wetland and dryland archaeology, and in particular within the differing theoretical approaches taken by the two sub-disciplines. The main driver for this disparity is the fundamental difference in the nature of the archaeological evidence. Not only do wetland and intertidal sites permit a much higher survival of organic artefacts and palaeoenvironmental evidence, but also they often have a much higher abundance and clarity of evidence. This abundance of evidence has often led to a more empirical approach in recording and describing wetland sites than would be taken within dryland archaeology. The alluring and powerful aesthetic of many of the objects recovered in wetland archaeology allows for more descriptive publications focusing on the artefacts themselves rather than their wider meanings. The focus of wetland studies is therefore often confined to a site level, with little integration of the evidence with the surrounding dryland landscape. Where theory exists in wetland archaeology, it is most often in the form of environmental determinism. The abundance of palaeoenvironmental evidence allows, and indeed encourages, this approach. The isolation of wetland sites from wider landscape and societal context leaves little room for socio-economic or theoretical approaches.

Whilst wetland archaeology can be criticised for having a narrow and site-based focus, paradoxically the opposite is also true, with wetland and intertidal sites compared often compared to each other on an international scale, This has created a sub-discipline more focussed and more willing to draw comparisons of sites at a global level than to investigate and explain the interaction with local dryland sites and landscapes. Thus we get comparisons of activities such fishing and its associated technologies at a global level, with little local or regional context (See Section 2.10.2 below).

Some successful attempts to integrate wetland and dryland archaeology should be noted, such as the work on the Flag Fen Basin, Cambridgeshire (Pryor 2013), the integration of wetland and dryland environmental evidence at Sutton Common, Yorkshire (Ayala *et al.* 2007) and the intertidal and surrounding drylands of the Severn Estuary, Gloucestershire (Bell 2007b). On a wider theoretical level, an attempt was made by Van de Noort and O'Sullivan (2006) to rectify some of the disparity between the approaches taken in wetland and dryland archaeology. This was heavily critical of the lack of integration by those working within wetland archaeology, but criticism can also be levelled at dryland archaeology which has a tendency to be less descriptive and occasionally overly concerned with rooting sites in a particular theoretical grounding. There is a difficulty in integrating the resolution of evidence, in particular the environmental evidence, and in describing how theoretical approaches that tend towards the macro scale can be applied at individual sites. As a starting point, wetland and intertidal sites can and must relate their evidence to wider landscape, in terms of theory, methods and practice.

2.10.2 Difficulties of identification and classification

Several authors have attempted a classification system for the recording and study of fish traps. These have ranged from the global (Von Brandt 1984; Gunda 1984) to the regional (Bannerman and Jones 1999; Turner 2005; Memmott *et al.* 2008). Classification systems such as these are highly problematic as they create a rigorous and inflexible system that does not easily accept sites or structures that vary from the norm. Further, a generalised global classification draws attention away from the cultural settings in which the structures were created and the individual societal and topographical pressures that caused their development. Global studies of fishing technologies, such as that of von Brandt (1984) and Gunda (1984), mainly focus on an ethnographic study of the use and construction of traps, and as such, can be seen as problematic in their application to historical or archaeological structures.

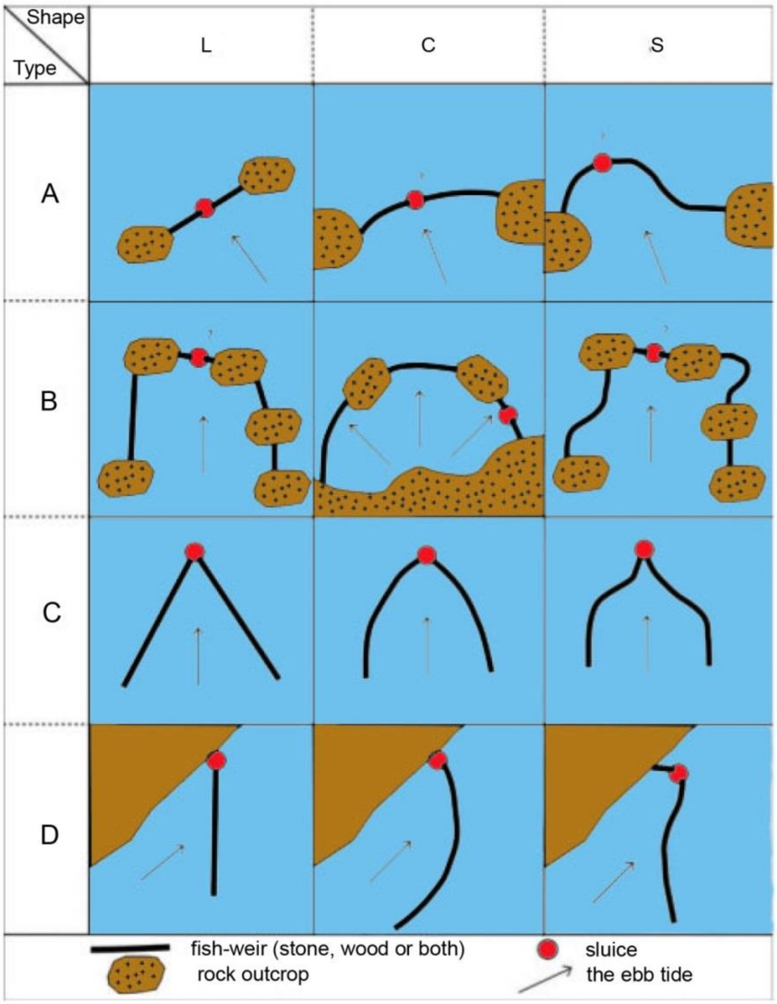

Figure 23 - A proposed system for the classification of intertidal fishing structures based on their two-dimensional morphology developed by Langouët and Daire 2009)

Fishing structures are most typically defined either in terms of their shape or in terms of the material used to create them. Classification by shape or form is useful in being able to quickly define a structure (e.g. **Error! Reference source not found.**), but can lead to the grouping of structures that otherwise have no commonality. Fishing structures have also been categorised in terms of the material used in their construction, most often into stone, stone and timber, and timber (Turner 2005). Classification by material can, however, be distracting in wider landscape studies of fishing structures; fishweirs from the upper Severn Estuary that are mainly timber built would be placed in a separate category from contemporaneous structures in the lower estuary, but would be placed in the same category as Mesolithic fishing structures from elsewhere. Often the choice of materials used in the construction of weirs reflects local geology and availability of materials, however, the argument can be made that in some cases heavier materials are selected for areas with a more dynamic tidal regime (Turner 2005).

A more important question in the study of fish catching methods might be what is the trap designed to catch? Very few classification systems attempt to address this issue, yet addressing the issue of species in some forms of trap may show a greater continuity of fishing practices within a landscape than merely classifying the type of trap used. For example within the Severn estuary there is a marked switch in form from the archetypal V-shaped weir, to V-shaped collection of stakes supporting large baskets (putts), to ranks of posts supporting rows of smaller baskets (putchers) arranged on top of each other (Jenkins 1984; **Error! Reference source not found.**).

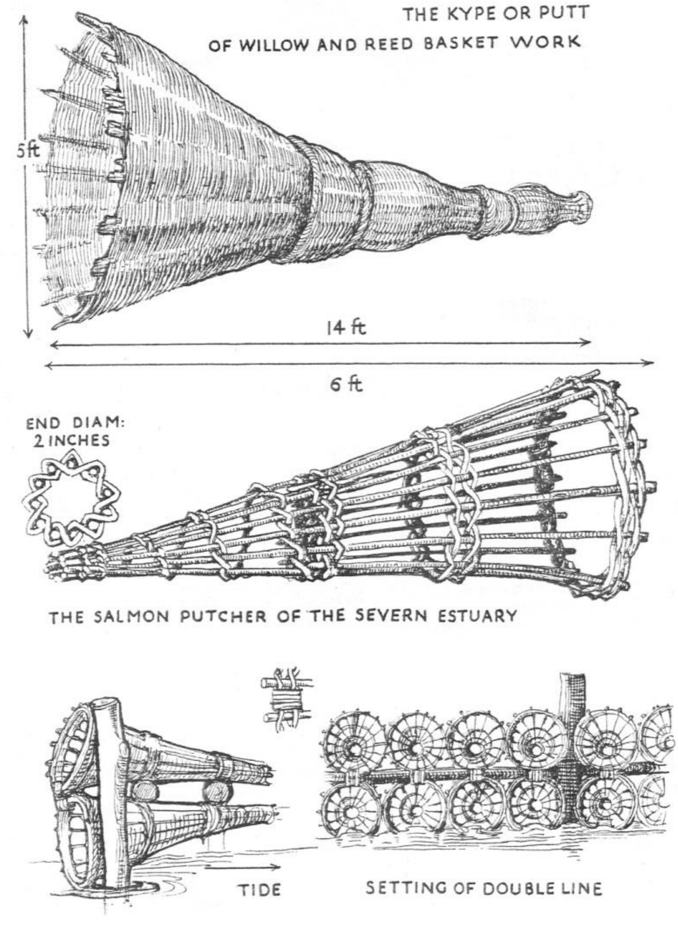

Figure 24 - Drawing of the putts and putchers in use on the Severn Estuary during the mid-20th century (Davis 1958)

This transition shows continuity both in the construction (all involve the use of stakes and wattle/weaving), and in species of fish being trapped, but a radical change in plan and structural form. A division of these traps by morphology fails to address some aspects of the continuity of the local traditions and skills.

The species being targeted will also influence the shape, placement and orientation of the trap. The regular and predictable nature of tides means that fish within the intertidal zone, both resident and migratory, have strongly entrained behavioural and physiological rhythms (Horn *et al.* 1999). Consequently, the pursuit of such fish manipulates these rhythms, using the movement of both tides and fish to maximise yields. Larger fixed fishing structures such as weirs are orientated with the apex pointed in the direction of the ebb tide. As fish move towards the shore to feed they then become trapped behind the structure by the receding waters. In some cases the specific species being pursued influences the orientation of the trap upstream or downstream. Migratory fish are nutritionally most valuable just prior to beginning their migration and both weirs and baskets can be orientated to exploit this. Catadramous species such as eels and lampreys, migrate from freshwater to the sea to spawn, and so can be caught by baskets with their mouths facing upriver. Conversely, traps orientated with their mouths facing downriver can be used to catch anadramous species such as salmon, trout or sturgeon, which move from the sea to freshwater to reproduce. The size of the weave used in the panels or netting of a fixed trap can also indicate its intended target. The average distance between warps can indicate which species of fish was being caught – weirs from the Oregon coast had spacing large enough to allow the passage of smaller fish such as herring or smelt but close enough together to catch salmon (Byram 1998). This spacing can also indicate not only the species being pursued but also regulation of fishing practices. Legislation from the medieval period relating to fishing in the Thames specified a minimum gauge in netting and traps in order to preserve stocks by allowing younger fish to escape (Smart 2003). However, the targeting of specific species implies a seasonal procurement of fish in large hauls, and is more representative of the last few hundred years of commercial fishing. Studies from pre-industrial Californian traps show that over half the fish caught consisted of a wide range intertidal species (Horn *et al.* 1999) whilst lists of fish from medieval documents and fish bone assemblages from archaeological sites show a wide variety of species being consumed. Bone evidence from sites also implies that species were caught off-season, suggesting that some traps were used all year round, rather than specifically targeting seasonal migration (Bødker-Enghoff 2000).

The position of fixed fishing structures within the tidal frame could be used to establish not only what species is being pursued, but also to act as an indicator for relative sea level at the time of the trap's construction. Work by Bannerman (2011) has attempted to use the position of fish weirs within the tidal frame to establish its contemporary relative sea level.

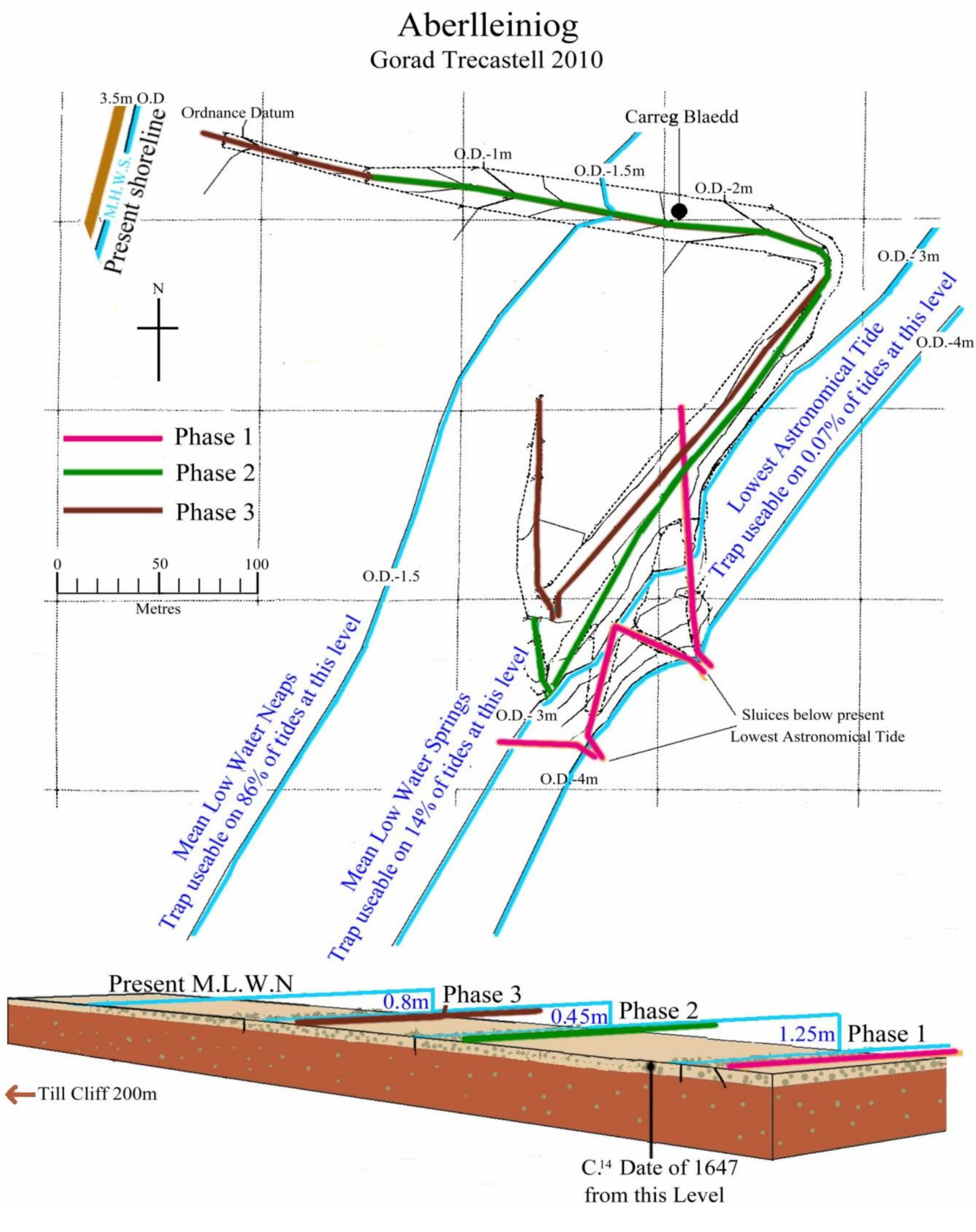

Figure 25 - Diagram showing the usability of coastal fish weirs during the various tidal states at Aberlleiniog, Anglesey, Wales (Bannerman 2011)

Bannerman stated that for maximum efficiency the apex of a fish weir should be just above the mean low water neap tides, allowing its operation on more than 95% of low tides, vital not just for efficiency but also for repair and maintenance (**Error! Reference source not found.**). This theory may help to explain the rebuilding or moving of fish weirs leading to the complexes of fishweirs at different positions within the tidal frame. However, Memmott *et al.* (2008) has documented similar complexes in the South Pacific that co-exist at different heights within the tidal frame in order to maximise the yields from different tides, with those built to utilise the high and low astronomical tides usable for only a small percentage of the year. Although these weirs exist in a climate with a more extreme range in tides, the principal could be extended to northwest Europe and may help to explain those structures currently below mean low water (See Chapter 5 below).

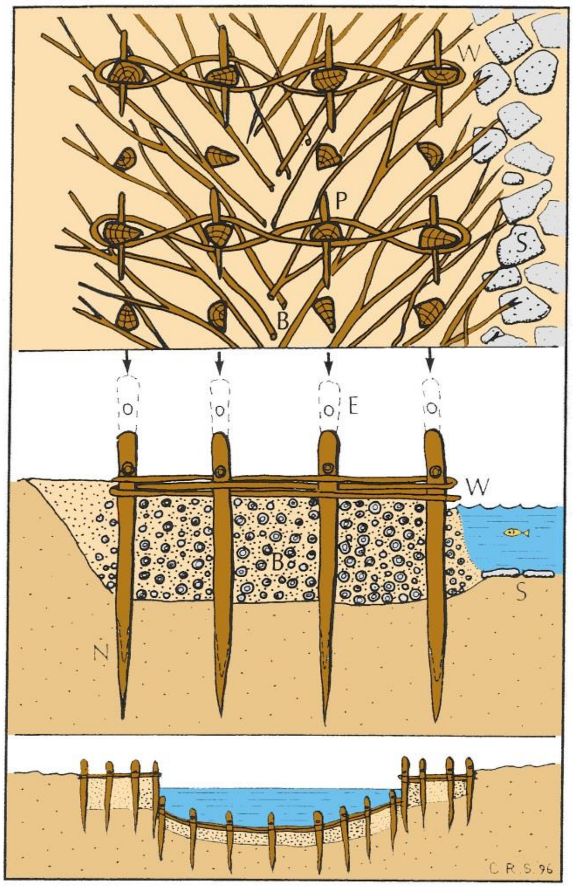

Figure 26 - Plan and section of a 'kid-weir' or 'brush piling', a structure used to trap sediment and alter river flow in the River Dove, Derbyshire (Lord and Salisbury 1997)

The erosion of most of the extant organic material means that most intertidal structures are recorded and categorised in plan form rather using a 3-dimensional approach. This 2-dimensional recording of structures is insufficient in two ways. Firstly, as noted above, similar form does not necessarily reflect similar function. The abundance of wattle and post as a construction method, and its sometimes amorphous quality raises the strong possibility of misidentification of structures. Within wetland areas well-made hurdles were used to create walkways, as they were easier to carry than bundles of brushwood and had a much greater surface area (Brunning 2001). Because of this, prehistoric wattle panels in England found within an intertidal context are most often interpreted as being paths or trackways, whilst in Denmark the same structures would be interpreted as fish weirs (Smart 2003). Wattle structures were also used to accumulate sediment in order to create a revetment to protect riverbanks or ports. The use of brush piling is known from both archaeological and historical sources, and involves the pinning of brushwood or wattle to the sides and beds of rivers and shorelines to slow down flow and encourage the accumulation of deposit (**Error! Reference source not found.**). Lord and Salisbury (1997) report such structures being known from the Trent, Somerset Levels and Romney Marsh in Kent, with a further site known from the River Dove in Derbyshire (Southgate *et al.* 1999).

Hurdle-work was similarly used in the construction of waterfronts, such as that excavated at Reading (Rackham 2010). Such a structure has been recorded in the medieval port of Dublin, formed of two diverging rows of posts meeting in a V-shape (O'Sullivan 2000), which in plan form could easily have been interpreted as a fishweir. Secondly, recording and analysing intertidal structures in plan form divorces the structure from its topographical and tidal context. The influence of topography and natural features has a crucial influence in defining the shape of the structure (Memmott *et al.* 2008), and likewise the tidal range, energy and direction of ebb plays a large part in defining the structure's form.

2.10.3 Dating of structures

Research into intertidal fishing structures has in some ways been hampered by the uniformity in the design and construction of weirs and baskets both spatially and temporally. Examples of fish weirs and baskets are known almost universally throughout the world. Within the British Isles sites are present in Ireland (O'Sullivan 2005), Northern Ireland (Mitchel 1965; McErlean *et al.* 2002), Scotland (Ceron-Cerrasco 2005), Wales and England. At a European level in Denmark (Bødker-Enghoff 1991; Smart 2003), France (Mordant and Mordant 1992), Germany , Russia etc. Sites are also known from the Middle East (Beech 2004), Japan (Matsui 1992) and Australia (Memmott *et al.* 2008). In North America, sites have been documented in Canada (Stevenson 1998), Alaska (Moss and Erlandson 1998), Boston (Decima and Dincauze 1998), Oregon (Byram 1998) and Montana (Chaney 1998).

Many woodworking techniques have changed little in the past 6000 years (Brunning 2001), likewise the basic forms of technology used in fishing, both fixed structures and portable items such as hooks, have remained remarkably consistent in their appearance over this time (Smart 2003). This has created a major issue in the study of fixed fishing structures. Although the development of dendrochronology and OSL dating has provided mechanisms for scientifically dating both wooden and stone-built structures, these have not, as yet, been rigorously applied to the study of fixed fishing structures due in part to their sheer number. Consequently, a large number have traps have been typologically dated by form, or dated by relation to geological deposits rather than having firm individual dates.

2.10.4 Lifespan

As yet no firm figures exist for the lifespan of fishing weirs. Although Jenkins (Jenkins 1984) noted that larch used in putcher ranks on the Severn lasted around 10 years before requiring replacement, with elm lasting up to 40, these figures refer to very specific structures and wood types. Furthermore, estimating the survival of individual elements within a structure does not account for its overall lifespan, as it does not take into consideration phases of repair. An intensive dendrochronological or experimental approach is needed to properly address these issues. Understanding the lifespan of a weir would not only help to contextualise the level of investment in the structure, but also help to map its usage in relation to surrounding structures. This is particularly important at sites such as Blue Anchor Bay, Somerset (Figure 27) where it is unclear if the numerous overlapping structures were consecutive or concurrent.

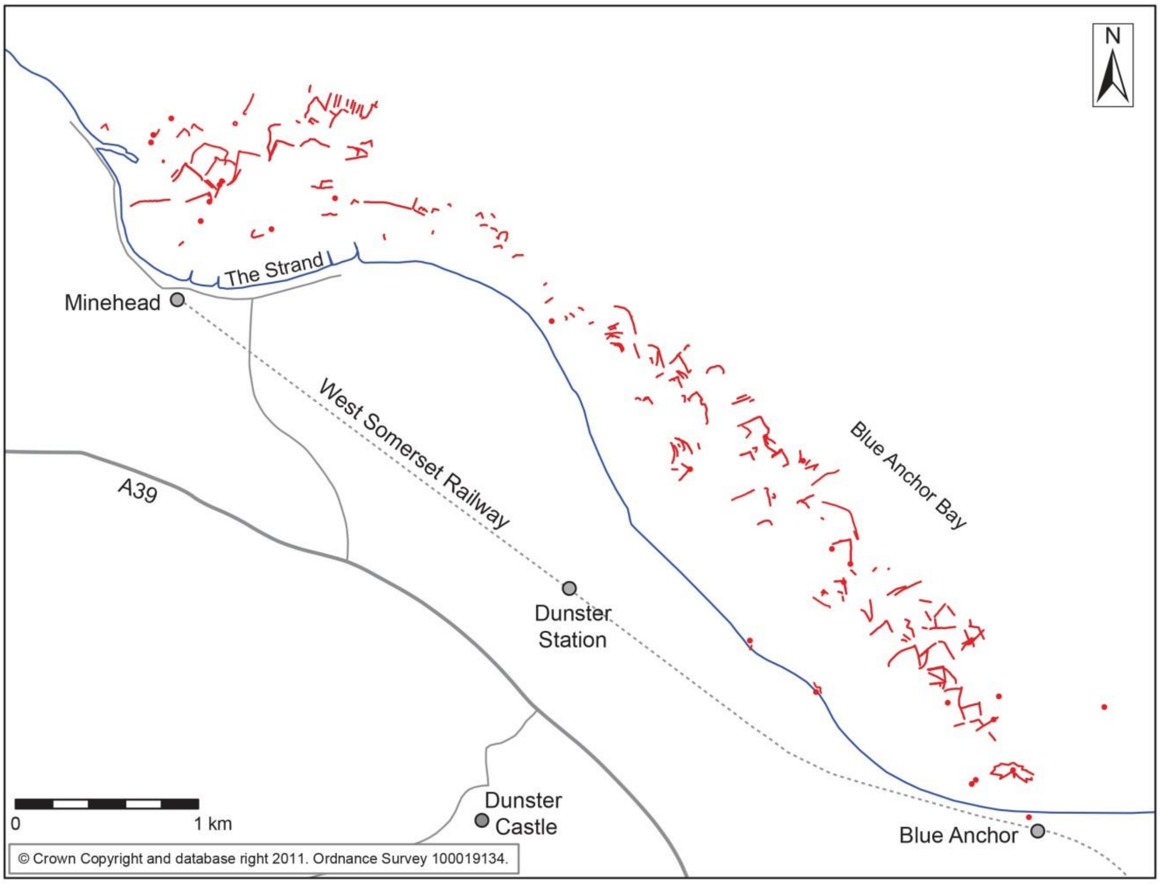

Figure 27 - Survey of the numerous fixed fishing structures in Blue Anchor Bay, Somerset compiled as part of the Severn Estuary Rapid Coastal Zone Assessment Survey (Chadwick and Catchpole 2013).

2.10.5 Ethnographic comparisons

As mentioned above, earlier approaches to the study of past fishing practices have often used ethnography or historical ethnography to fill in the gaps in our knowledge if the use of fishing structures. The validity of such approaches is always in doubt. Most societies that still fish using these methods are radically different in structure to past societies. However, ethnographic approaches can help to understand some of the less tangible aspects of the operation of fixed fishing structures. Smart (2003) has sought to use both historical and modern examples to elucidate the used of prehistoric structures. Memmott *et al.* (2008) have also drawn value from the ethnographic studies of fishweirs, correlating their typology and usage with tribal divisions.

2.10.6 Fishweirs and geomorphological processes

Much in the same way as they were used to create brush-piling of 'kid-weirs', fish weirs are a contributing factor to the accumulation of sediment, and work as a filter and accumulating debris and sediment. In particular, where these structures are placed within estuaries they collect materials from both marine and fluvial processes and can change patterns of intertidal channels and affect sedimentary processes (Putnam and Greiser 1993; **Error! Reference source not found.**).

The processes described by Putnam and Greiser (1993) explain the creation of salt-marsh above disused weirs, a process that can be seen to be occurring at Aust on the east bank of the Severn. These processes are important for two reasons, firstly, they can explain an apparent lack of fishweirs where they should occur, as accumulation of sediment buries or masks structures. In addition, this process raises questions about the maintenance of weirs, and probable causes for their abandonment, although whether weirs were abandoned due to accumulation of sediment, or whether sediment accumulated post-abandonment would be a difficult question to answer.

A better understanding of geomorphological processes could help to contextualise the original setting of certain fishing structures. As seen above (Section 2.2.4), fishweirs have a direct relation to relative sea level at the time of their construction (Bannerman 2011). Similarly, within estuaries, fishing structures directly relate to the tidal frame, and a moving channel edge will have a direct effect on their efficiency and usage. Sites within the Severn Estuary, dating to the historic period, have been recorded up to 450m out from mean high water level, meaning that the channel must have moved significantly, forcing their abandonment.

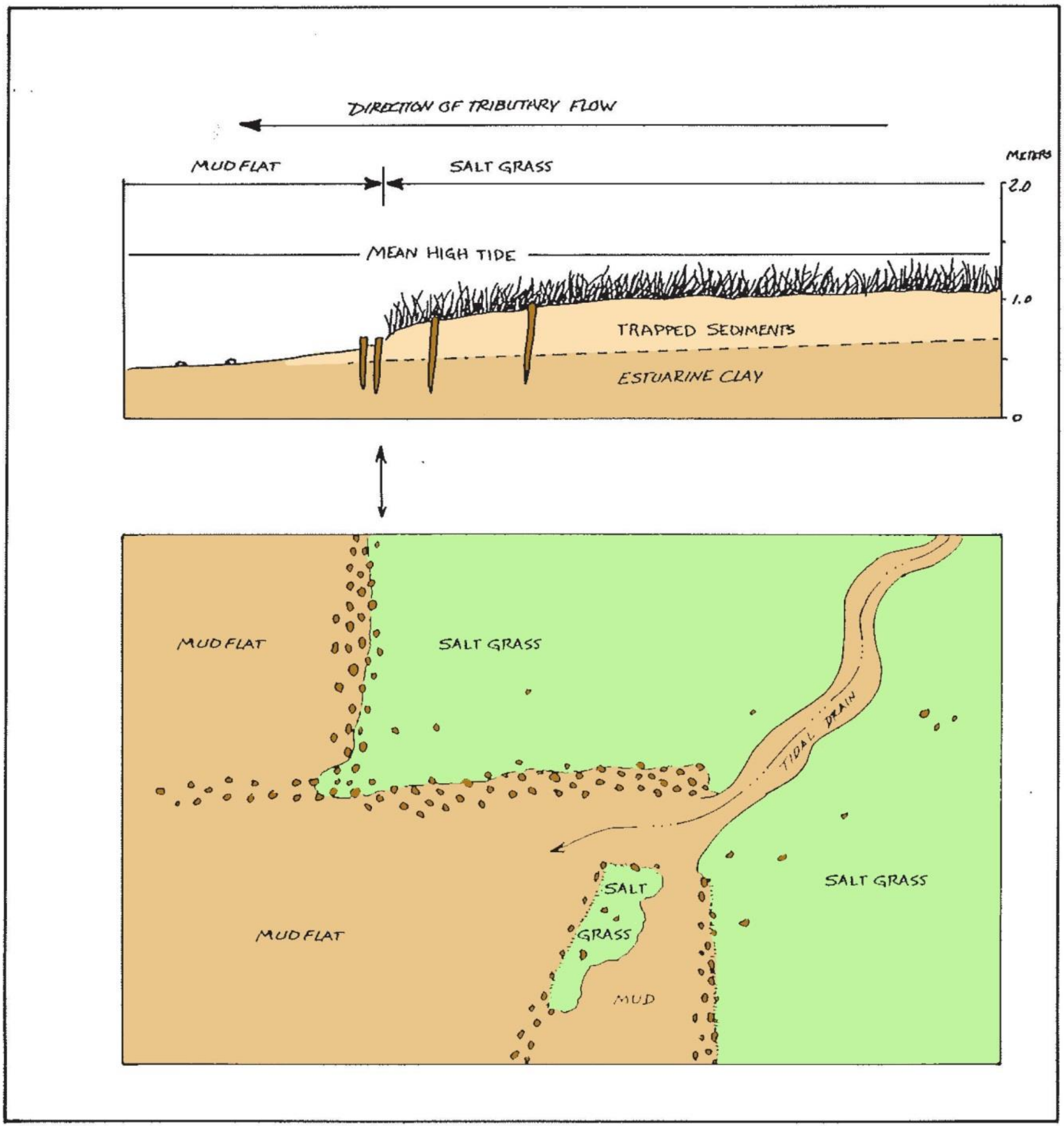

Figure 28 - Plan and section showing sediment accumulation and the subsequent development of salt marsh behind historic fishweirs on Prince of Wales Island, Alaska (Putnam and Greiser 1993)

Chapter 3: Terrestrial Laser Scanning and Intertidal Archaeology

And in all Coafts, what Moon maketh full Sea, and what way, the Tides and Ebbs, come and go, the Hydrographer ought to record. The founding likewife: and the Chanels ways: their number, and depths ordinarily, at ebbe and floud, ought the Hydrographer, by obfervation and diligence of Meafuring, to have certainly known…

Dr John Dee 1570

3.1 The Development of Terrestrial Laser Scanning

The first solid state ruby laser was developed in 1960 and during the following decade laser technology developed rapidly (Large and Heritage 2009). At a very early stage, the realisation was made that the technology had applications for measurement by accurately recording the length of time that it took an emitted laser beam to reflect from a surface and return to its point of origin. By 1966, lasers were being used to take highly accurate measurements within the laboratory (Large and Heritage 2009), by 1968 optical triangulation systems were being employed for capturing three-dimensional data by extrapolating measurement from the triangulation of the beam's reflection from a surface, and by the 1980s a number of laser profiling systems had been trialled. (Beraldin *et al.* 2010)

Simultaneously, outside of the laboratory, within the survey and construction industries lasers were rapidly adopted as a tool for accurate distance ranging (Large and Heritage 2009), and by the 1970s began to replace other forms of emitted light in optical surveying equipment such as tachaeometers and EDMs (Petrie and Toth 2009b). At the same time airborne laser bathymetry, first proposed in the 1960s as a possibly way of detecting submarines, was tested and by the 1980s operational systems were in place (Crutchley and Crow 2009). The early 1990s saw the development of SHOALS - one of first fully operational airborne bathymetric systems (Petrie and Toth 2009a). As early as 1965 laser ranging techniques had been trialled from an airborne platform for laser profiling of terrestrial topography (Petrie and Toth 2009b). The development of laser scanning, which involved the addition of a rotating mirror or prism to allow a wider field of view for data collection, permitted the collection of swaths of data from airborne platforms (Petrie and Toth 2009b), leading to the development of airborne laser scanning (ALS). By the mid-1990s the integration of airborne laser scanners with global navigation satellite systems (GNSS) and inertial navigation systems (INS) provided sufficient accuracy for it to be used as a reliable topographical tool (Petrie and Toth 2009b). The advances made within airborne laser scanning led to the development of terrestrial laser scanning (TLS) by 1999 (Large and Heritage 2009). By the mid-2000s terrestrial laser scanning had been incorporated into mobile mapping systems (MMS) (Petrie and Toth 2009c) integrating with, and in some cases replacing, existing technologies to provide a rapid and highly accurate means of collecting high-resolution topographic data.

Laser scanners can be broadly separated into two types, time-of-flight and continuous wave scanners. Time-of-flight scanners work by using a pulse-echo system to measure the precise time interval between a laser being emitted from the scanner and its return to the instrument after reflection from a surface (Petrie and Toth 2009b). They are regarded as being highly accurate and have a workable range of between 1-200m (although this varies highly depending on the system used). Time-of-flight scanners have been released with a workable range of several hundred metres, however as the range increases the level of resolution and accuracy of the information gathered decreases. As a result, scanners of this type are most often used within larger landscape surveys, and are usually limited to the aggregate and mining industries. Continuous wave or phase-based laser scanners emit a continuous laser beam. The reflection of the beam is received by the instrument and the distance travelled is calculated by comparing the phase difference in the sinusoidal wave pattern of the emitted and received beam (Petrie and Toth 2009b). The use of a continuous wave places a limitation on the range of the scanner, making them most applicable where distances measured are less than 100m (Petrie and Toth 2009b). In general phase-based laser scanners are considered to have a comparatively lower accuracy than time-of-flight scanners, although given the relatively short range at which they are used this difference in negligible (Petrie and Toth 2009b)

3.2 The Place of Terrestrial Laser Scanning in Metric Survey

A diverse range of survey techniques fall under the banner of 'metric' or 'measured' survey, each of which varies in the form, scale and quality of data collected. Any approach that uses metric survey must therefore justify the approach taken, as the aim of the survey should always define the selection of the technology used, rather than the technology available limiting the scope of the survey. No single method or technique of survey is able to give fully satisfactory results in all cases, and the combination of differing techniques is in most cases essential. The differing nature of the data provided by each technology means that there must be a critical understanding of the limitations of the techniques involved (Grussenmeyer *et al.* 2008).

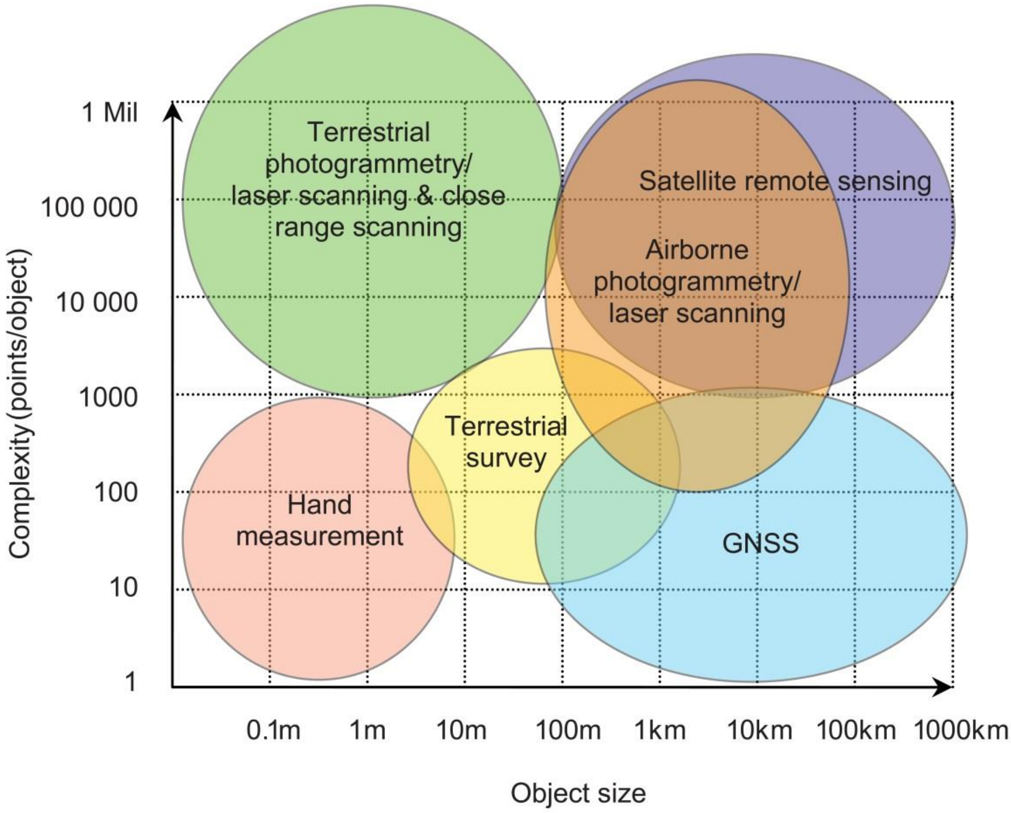

Figure 29 – Diagram comparing the range and complexity of different metric survey techniques (After Mills and Andrews 2011).

Several principle factors influence the approach and choice of technology used in the application of metric survey:

1. Range – The maximum distance from which a measurement can be taken without compromising resolution or accuracy.
2. Resolution – The density or spacing of points or measurements.
3. Accuracy – The closeness of the measurement taken to the actual value.
4. Precision or 'repeatable accuracy' – The closeness of repeatability of a measurement to the actual value.
5. Operational issues involved with the survey. These can include anything from time limitations to logistical costs to the weight of the equipment. As will be seen below (Section 3.6) environmental conditions can play a significant role in the ability to operate certain types of equipment in the field, and in the performance of certain types of technology in the field.

One of the chief divides in survey technology is between range-based modelling (RBM) and image-based modelling (IBM). Range-based modelling refers to the direct measurement of three-dimensional geometry through the use of active electromagnetic sensors, and encompasses total stations (which use both infrared and laser sensors) and laser scanners (Lo Brutto and Spera 2011). These technologies are referred to as 'active' sensors in that the target is illuminated by the sensor itself, and measurement is therefore independent of external illumination (Wehr 2009). IBM is based on the use of image matching techniques and rectification to create a three-dimensional context from which models can be made, and forms the basis of optical triangulation scanning, photogrammetry and structure from motion (SfM) techniques. IBM techniques use 'passive' sensors, and so are limited by external radiation or reflectance. Range-based modelling provides much better metrics and quality of data than image-based modelling, but has a higher cost both financially and temporally. IBM techniques have thus become revalued (Lo Brutto and Spera 2011), and are often the preferred form of survey used within the heritage industry due to their low start-up costs. The advances in digital photography and associated software mean that historic problems with the cost and specialised nature of photogrammetry are no longer prohibitive (Boochs *et al.* 2007), and the vast improvement in digital photography and the development of computer automation to generate 3D geometry from imagery have made these technologies much more appealing (Briese *et al.* 2012). In particular, the ability of more recent software to extrapolate point clouds from the imagery has led to a much greater ability to integrate RBM and IBM datasets. This greater integration has made it easier to integrate orthophotography into GIS based programs, draping the resultant imagery over the ALS data to create realistic visualisations of landscapes (Habib 2009). Whilst not providing as high a level of resolution, accuracy and precision as range-based modelling techniques, the ability of technologies such as SfM to quickly capture large-scale landscape detail is hugely advantageous. However, it is not the intention of this thesis to focus on image-based modelling techniques as they do not strictly fall within metric survey, being indirect data acquisition methods which use images to extrapolate measurement rather than taking direct measurements themselves (Boehler et al. 2002).

The following subsections present brief descriptions of metric survey approaches, the style of data they produce and the limitations in their application.

3.2.1 Airborne Laser Scanning

Airborne laser scanning (ALS) works on the principle of pulse-echo laser scanning, with the measurement being derived by recording the time-of-flight taken by an emitted laser beam fired from an aircraft to reflect from the ground. ALS systems comprise three parts, a laser scanner module mounted on the underside of the aircraft, a GNSS system recording the position of the aircraft at the time of data collection, and an Inertial Navigation System (INS) which records the pitch, roll and yaw of the aircraft (Crutchley and Crow 2009). The GNSS and INS are used to calibrate the data gathered from the laser scanner and place them into a geo-referenced co-ordinate system. In operation, a laser beam is scanned across the surface of the ground perpendicular to the direction of the aircraft, which allows a measured swath of points to be recorded along the flight path of the aircraft. Adjacent swaths are pieced together to create a wider landscape model, with adjacent flight swaths overlapped in order to increase resolution and accuracy (Hofle and Rutzinger 2011).

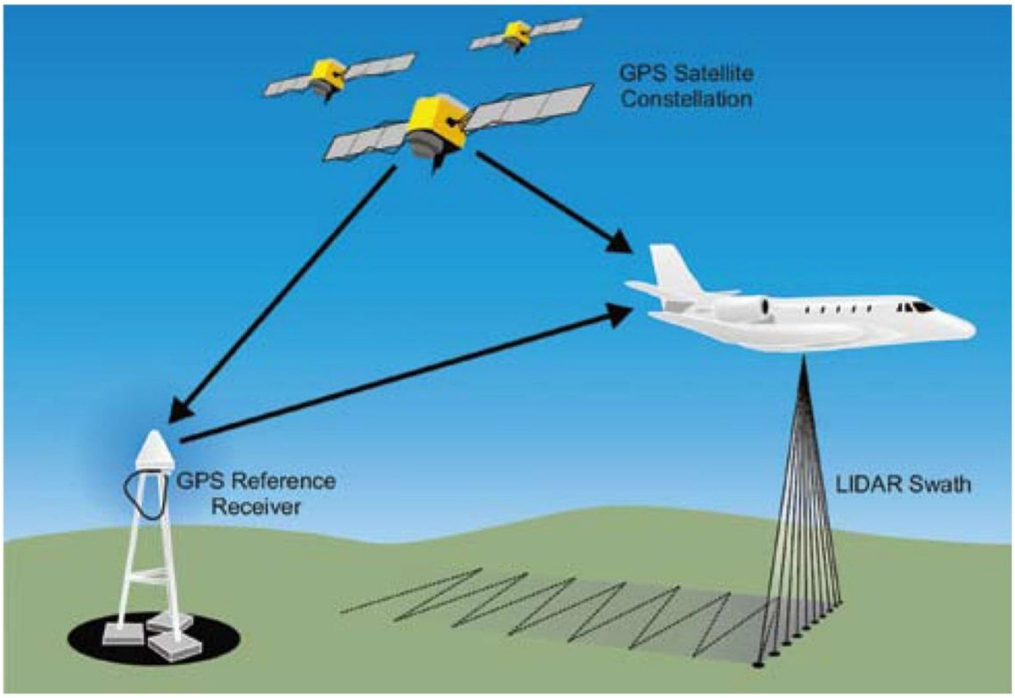

Figure 30 - Diagram showing the rectification of data gathered using airborne laser scanning (Crutchley and Crow 2009).

The resolution of ALS is most typically under a metre, with point densities of up to 0.1m or 100pts/m2. The horizontal and vertical precision of the resultant data is further dependent on the altitude of the aircraft during collection (Large and Heritage 2009). Additional control over the accuracy of the data is provided by communication with a fixed GNSS ground system, which rectifies that given by the GNSS on board the aircraft (Devereux *et al.* 2005; see Figure 30). Further control is provided by surveying a calibration area (a portable calibrated target of known dimensions and reflectance) at the beginning and end of flight in order to identify 'system drifts' (Wehr 2009). With these additional controls, ALS can produce measured points with a precision of 0.15m. (Large and Heritage 2009). ALS is most typically operated from aeroplanes, but can also be operated from helicopters or unmanned aerial vehicles (UAVs). This is advantageous as the aircraft's speed can be reduced to zero and the altitude lessened, allowing for a higher resolution of data collection. However, with the use of UAVs the weight of both the equipment and power source is a highly limiting factor (Charlton *et al.* 2009).

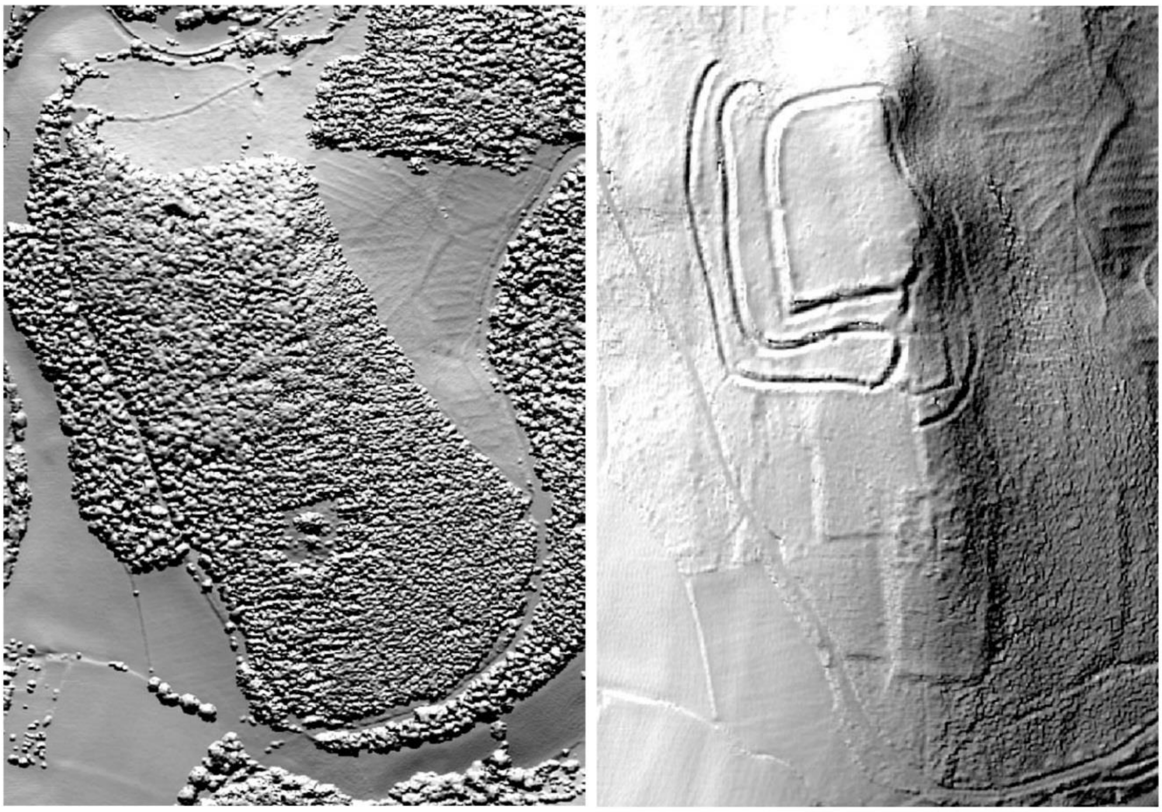

Figure 31 – Airborne laser scanning survey of Welshbury Hill in the Forest of Dean by Devereux *et al.* (2005), showing the digital elevation model (left) compare to the 'bare earth' or digital terrain model (right).The removal of the first-return pulse data revealed substantial earthworks and field systems underneath the woodland canopy.

The footprint of the laser spot generated by airborne laser scanning can be between 0.1m and 1.5m, and so frequently overlaps the edge of an object. When this occurs, responses are recorded for both objects encountered, and the scanner records the reflection of both the first-return and last-return pulse. This can be used to penetrate vegetation and record measurements for both woodland canopy and the ground below (Devereux *et al.* 2005). The first-return pulse data are used to create a digital elevation model (DEM), also known as a digital surface model (DSM). However, for the purposes of topographic and landscape study, a common form of processing involves the removal of buildings and vegetation from the dataset to create a digital terrain model (DTM). This is dependent on the last-return pulse data being collected, as the first-return pulse data is removed to create the DTM, or 'bare-earth' model (see Figure 31 above).

Within landscape survey ALS has the benefit of not being as limited as terrestrial laser scanning, total station and GNSS surveys in terms of areal extent (Large and Heritage 2009), and has vastly reduced the need for field survey in forested areas (Petzold *et al.* 1999). The use of the last-pulse returns also means that ALS can be a remarkably comprehensive landscape survey technique, with very few voids in the data caused by buildings or vegetation cover. However, there is no guarantee that the last-return pulse measurement has actually hit the ground

(Devereux and Amable 2009) which may lead to the creation of an erroneous bare-earth model. The type of vegetation can also have an effect on the quality of data gathered, with thick forest conifer plantations providing a coarser resolution and consequently a lower quality of DTM (Doneus *et al.* 2007), and in the case of particularly dense vegetation reducing the resolution of ALS data or obscuring the ground surface altogether (Devereux *et al.* 2005). ALS can be further constrained by atmospheric conditions such as cloud cover or fog, because of which it is often flown during the winter season as it the ensures maximum penetration of the canopy (Devereux *et al.* 2005), however this in turn can create issues with collection of data caused by precipitation and the reflectance of snow cover on the ground (Doneus *et al.* 2007).

Figure 32 - Palaeochannels in the Witham valley revealed by airborne laser scanning survey (Crutchley and Crow 2009)

Aerial survey has been a significant part of the archaeological study of the landscape since the 1920s (Crutchley 2009), and is extremely significant in archaeology as it is one of the few techniques available for the systematic (i.e. non-coincidental) discovery of new sites (Doneus *et al.* 2007). Initially, the resolution of the ALS data was not considered to be of use for the detection of archaeological features (Crutchley and Crow 2009), but advances in technology made it an appropriate tool by the early-2000s. and did not require rectification instead collecting an accurately geo-referenced point cloud (Shan and Toth 2009). This removed a large degree of the interpretative element of aerial survey (Doneus *et al.* 2007). The ability to virtually manipulate the resultant data set also meant that virtual lighting and hill-shading have provided a greater ability to detect features (Devereux *et al.* 2005). In 2001 English Heritage commissioned the Environment Agency to record ALS data at a resolution of 1m over the Stonehenge World Heritage Site, a site that had been heavily surveyed by a number of means including previous methods of aerial survey (Crutchley 2009). As it was a very intensively surveyed landscape, the ALS was not expected to pick up very much, and was instead intended to test the technology over a 'known' landscape. However, the survey added a large amount of detail to the known sites, and discovered entirely new features within the landscape, as well as tightening the positional accuracy of features recorded by previous aerial surveys (Bewley *et al.* 2005).

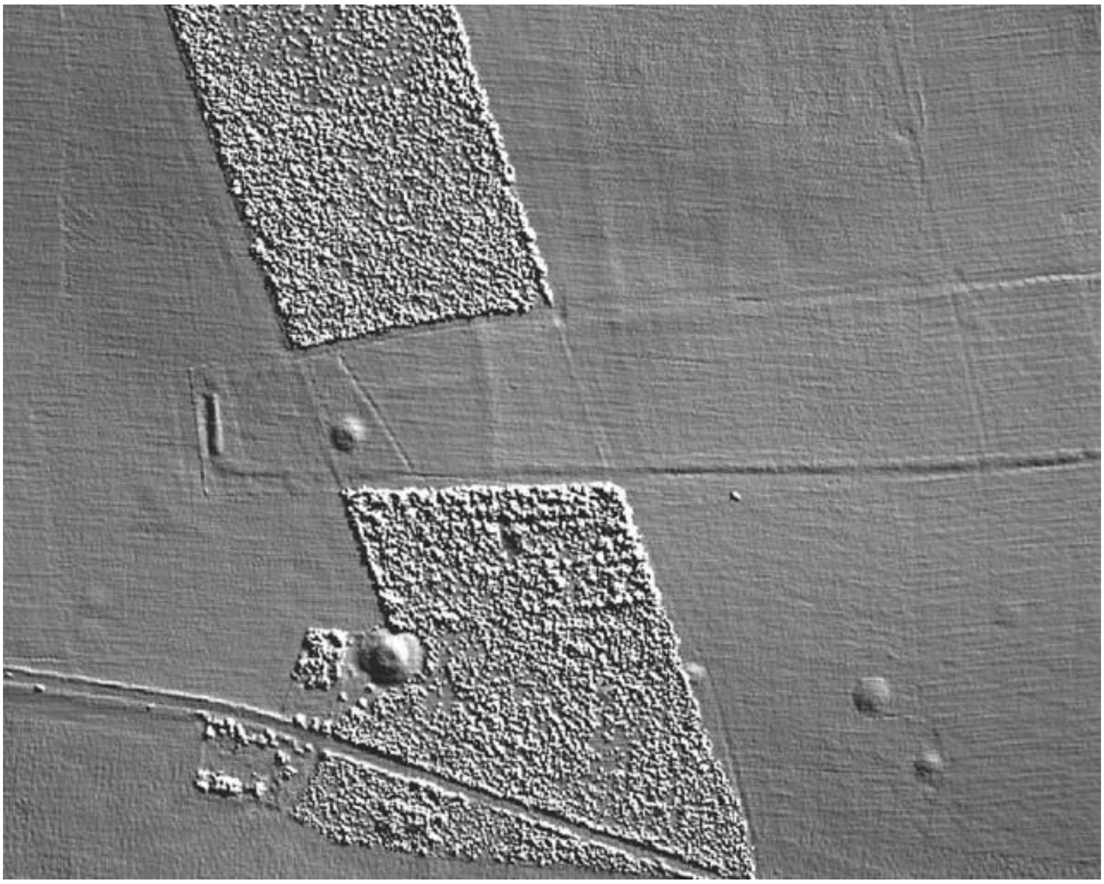

Figure 33 – Aerial laser scanning survey of the west end of the cursus in the Stonehenge landscape, illuminated from the north-east through the use of a 'digital sun' (Bewley *et al.* 2005).

The use of a 'digital sun' to illuminate features in ALS datasets has meant that very slight earthworks can be detected (Bewley *et al.* 2005), and the further use of Polynomial Texture Mapping (PTM), which combine a number of lighting sources across a virtual landscape has provided the ability to detect even more subtleties in the landscape (Goskar and Cripps 2011). The ability of ALS to penetrate vegetation has had a major impact in the archaeological reconnaissance of landscape (Doneus *et al.* 2007). Many archaeological sites and monuments, particularly those which are scheduled are covered by both deciduous and coniferous woodland making aerial and terrestrial survey difficult (Devereux *et al.* 2005). Again, such monuments are considered 'known' sites, but ALS has proved able to reveal features such as field system boundaries, lynchets and tracks (Devereux *et al.* 2005), with the resolution of ALS survey making it possible to detect even subtle features such as ridge and furrow beneath the canopy (Sittler 2004). ALS has also proved to be a highly useful tool in the understanding of landscape change in its ability to record geomorphological variants in the landscape, with subtle differences in elevation highlighting the presence of palaeochannels. The detection of palaeochannels is highly useful not only in the description of landscape change over time, but in indicating the likely location of past settlement within the landscape (Crutchley 2009). However, a lot of processing is needed to identify these structures, and the success of the process is dependent on the age, structure and size of the channel (Possel *et al.* 2010). Landscape data garnered from ALS enables the further interpretation of the archaeological landscape through digital manipulation of the DEM. The ability to digitally remove surface features such as trees and buildings not only enables the recording of underlying archaeology, but viewshed analysis on the resultant DTM provides a better explanation of the topographic relationship between monuments (Bewley *et al.* 2005). The 'bare earth' model can be used in combination with techniques such as 'digital gardening' to give a much fuller understanding of past landscapes (Gearey and Chapman 2005). Advances in the technology and in its application to the historic environment has meant that a point spacing of >30/m² is now possible, leading to a much higher resolution recording of archaeological monuments (Fujii *et al.* 2012).

Within the wider study of coastal areas, airborne laser scanning has been used extensively within the earth sciences for the measurement of dunes and tidal flats with the data produced used as a baseline for the determination of coastal change and erosion (Wehr and Lohr 1999). ALS data has also been used to extract tidal channel networks and to create predictive models of landscape and tidal change (Hofle and Rutzinger 2011). Whilst these techniques have not been directly applied to the study of archaeological sites, they provide an environmental context within which coastal and intertidal archaeology can be predicted and monitored. Similar projects within riverine environments have been used to develop methodologies for predicting the preservation of archaeological remains (Howard *et al.* 2008).

3.2.2 Bathymetric Airborne Laser Scanning

One of the early driving factors in the development of airborne laser measurement was the attempt to use the burgeoning laser technology as a means of detecting submarines. To this end airborne bathymetry was conceptualised, with the first successful systems being brought into use in the 1970s (Irish and Lillycrop 1999). Bathymetric airborne laser scanning uses both a green laser to record the depth of sea floor, and an infrared laser which reflects from the surface of the water (Crutchley and Crow 2009). Depth is calculated from the time it takes the green laser to travel through the water, with compensation made for waves or surface disturbance. The resolution and accuracy is not as great as that of ALS, but it is mainly used as a topographic tool for mapping the depth of sea floor, so this is less of a limitation in its application (Irish and Lillycrop 1999). Bathymetric ALS is most efficient in shallow water where traditional survey methods cannot be applied and, depending on environmental conditions, can penetrate to a depth of up to 50m (Beraldin *et al.* 2010). New high resolution bathymetric techniques are also being used to map the topography of floodplains, estuaries and coastal areas to a depth of up to 7m with a resolution of up to 25 points/m2 (Steinbacher *et al.* 2012). However, these techniques are inhibited by factors such as turbulence of flow and by water contained a great deal of suspended sediment, both of which are a frequent problem within the intertidal zone (Hofle *et al.* 2009). Bathymetric ALS has been applied to a limited number of intertidal and marine archaeology as marine geophysics often provides a more useful solution at most sites. However, recent work by Tian-Yuan Shih *et al.* (2014) and in particular Doneus *et al.* (2015) has shown that, with the right conditions, there is a high potential for the application of the technology in areas with substantial intertidal or shallow water archaeology sites.

3.2.3 Global Navigation Satellite Systems

Global Navigation Satellite Systems (GNSS) refers to the use of satellite technologies such as the United States GPS (Global Positioning System) and Russian GLONASS (Global Orbiting Navigation Satellite System) satellite constellations for the purposes of terrestrial navigation and mapping. GNSS equipment works by receiving a directional microwave radio signal from a satellite in orbit, signals transmitted from a network of such satellites are used to triangulate the position of the receiving equipment on earth (See Figure 34 below). The receiver is mounted on a survey pole that can be positioned above features to map their location. Inaccuracies caused by movement of the survey pole are rectified by using another receiver mounted on a base station at a fixed location, which monitors fluctuations in accuracy and rectifies the position of the survey pole. More recent systems rectify inaccuracies in the data through the use of additional triangulation using mobile phone networks, dispensing with the need for an onsite base station.

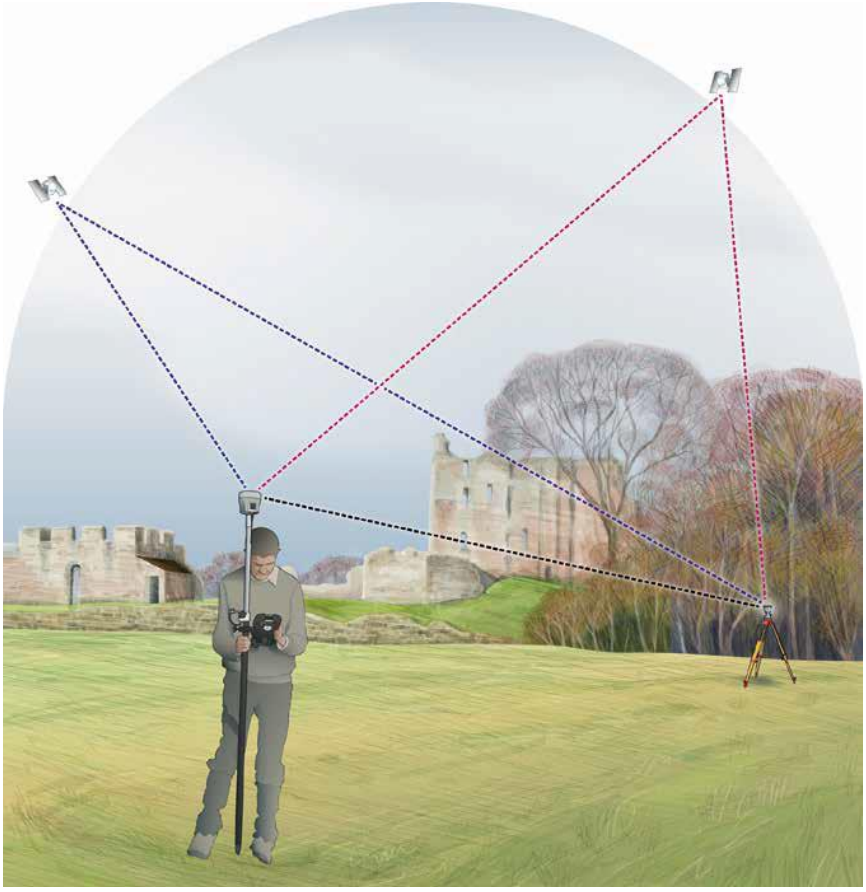

Figure 34 – The principles of GNSS recording. The location of a survey pole is triangulated using microwave radio transmissions from satellites, with inaccuracies in the data rectified through the use of a fixed base station (Pearson 2015).

GNSS is essentially a landscape mapping tool, it does not have the ability to record complex three-dimensional forms, but rather is used to record topography. GNSS is more flexible as a topographic survey method than total station survey as it does not rely on line of site, with the additional advantage that ground control does not need to be permanently established or referred to; removing the need to reference a bench mark. In addition, the equipment is extremely portable, fast to operate, and can instantly convert established positions to a range of mapping projections. GNSS is not only used as a topographic survey tool in its own right, but also to georeference surveys conducted with total station and terrestrial laser scanning equipment. The disadvantage of the technique is that it requires sufficient coverage from either satellite or mobile phone networks, meaning that in areas where the sky is obscured (such as quarries or forests) the equipment fails to achieve a high enough level of accuracy to be of use.

Within archaeology, GNSS survey is extensively used for landscape and topographic survey, as it allows the user to roam through the landscape without needing to reset equipment or rely on line of sight.

3.2.4 Terrestrial Laser Scanning

Terrestrial laser scanners merged the developing technologies within airborne laser scanning with that of total stations (Petrie and Toth 2009b). Early terrestrial laser scanning systems consisted of a scanning mirror mounted on a tripod, and had a stationary capture window with a limited field of view. The scanner had to be manually moved or rotated to capture additional data and the resulting datasets stitched together after the survey was complete. The development of the panoramic terrestrial laser scanner involved mounting the scanner head on a rotating base, so the head of the scanner rotated 360° around the vertical axis while the mirror scanned up and down, giving the terrestrial laser scanner a nearly full panoramic field-of-view, excluding only the area directly beneath the scanner. The development of terrestrial laser scanners with a 360° view enabled the recording of a much larger volume of data in a smaller number of set ups.

Terrestrial laser scanning follows similar principles to airborne laser scanning, but differs in its application in several ways:

1. In TLS, scans are captured from a stationary location allowing a much higher level of accuracy in the resultant data
2. Many TLS systems incorporate phase-based or continuous wave (CW) technology allowing for more rapid data collection
3. TLS rarely collects last-return pulse information and cannot be filtered in the same way as ALS

The development of terrestrial laser scanners by companies such as Leica and Trimble, with strong survey backgrounds has led to the integration of GNSS and total station technologies and workflow, enabling TLS to be incorporated into standard survey practice. The latest models of terrestrial laser scanners are able to traverse in a similar manner to total stations, and geo-rectify their data through connection to GNSS control. Within traditional survey applications, terrestrial laser scanning has seen a rapid uptake. Whilst survey instruments such as GNSS and total stations have a low cost and power requirement, they exert a high demand on operator time and cost (Large and Heritage 2009), by contrast the higher investment costs of terrestrial laser scanning are offset by a vast reduction in time spent in the field, as well as increased accuracy, precision and resolution. As a result, companies involved with complex urban development and engineering surveys have been swift to adopt the technology.

3.2.5 Mobile survey technologies

Mobile laser scanning (MLS), which has also been referred to as 'kinetic laser scanning' and 'dynamic laser scanning', refers to a terrestrial laser scanner mounted on to a moving vehicle or platform. MLS systems have mainly been used terrestrially, mounted on trolleys, cars and trains, but have also been deployed on watercraft (Kutterer 2010). MLS is in effect a portable base from which to carry out stationary panoramic scans, in a method of data collection referred to as 'stop-and-go' mode (Kutterer 2010). These systems can be as straightforward as a wheeled tripod trolley, or involve one or two laser scanners mounted on a vehicle which remains stationary during scans and is then moved to next position, allowing for the step-by-step scanning of extended or elongated objects (Petrie and Toth 2009c). The advantage of this 'stop-and-go' technique over standard terrestrial laser scanning is that a high accuracy and resolution of data is maintained whilst providing a more portable system in the field. The development of high speed continuous wave terrestrial laser scanners and the affordability of GNSS-INS technology has led to the evolution of mobile laser scanning into mobile mapping systems (MMS) (Alho *et al.* 2011). Mobile mapping is defined as 'the task of capturing and providing 2D or 3D geometric environmental information using an imaging sensor which is attached to a moving platform' (Kutterer 2010). Prior to the introduction of terrestrial laser scanning, MMS systems used photogrammetry as the principle method of collecting 3D data (Petrie and Toth 2009c), and more recent systems have sought to integrate the two technologies within MMS (Briese *et al.* 2012). A clear distinction should be made between MLS and MMS. MLS should be taken to refer to a platform used to move a TLS from one set-up to another, whilst MMS is the continuous collection of data incorporating laser scanning, but also involving several other forms of technology. Mobile Mapping Systems use the so-called 'on-the-fly' mode of kinetic laser scanning. A terrestrial laser scanner is fixed at an angle scanning in 2D profile mode around one axis, providing x and y measurements on a plane. The z value is added by the vehicles trajectory, building a 3-dimensional model as the system moves along (Kutterer 2010). In this respect mobile mapping systems are similar in their construction to airborne laser scanning systems and typically comprise optical sensors (either laser scanners and/or digital cameras), a GNSS positioning and navigation unit for spatial referencing, radar sensors and laser measurement finders, and a time referencing unit (Alho *et al.* 2011).

Mobile mapping systems have had limited usage within archaeology to date due to the relatively recent development of the technique, and its potentially limited application to the study of archaeological sites. However, Briese *et al.* (2012) have used MMS to record a Roman monument called 'Heidentor' within the archaeological site of Carnumtum (Austria). Whilst their project was designed to test the application of the technology and was not specifically designed to record the site, the resultant dataset proves the possibility of its usage within the historic environment. MMS have not as yet been applied to the study of wetland or coastal archaeology sites, however, within the study of fluvial geomorphology Alho *et al.* (2011) have used a combination of ALS, MMS and static TLS to map and analyse change detection in point bars. The project faced comparable survey challenges to those of intertidal and wetland archaeology, including the high-risk element of surveying in a dynamic environment. A multi-system approach such as that applied by Alho *et al.* (2011) would permit the rapid coverage of a site whilst preserving the accuracy of the collected data. Mobile Mapping Systems provide a halfway house between airborne and terrestrial laser scanning, providing a higher point density and accuracy than that of airborne laser scanning, whilst covering a much greater geographical range than terrestrial laser scanning (Alho *et al.* 2011). MMS can provide topographical data on a scale of less than one decimetre, with an accuracy of ±0.15m (Alho *et al.* 2011). However, the accuracy is dependent on the quality of spatial referencing with some systems capable of providing an absolute accuracy of 50mm (Kutterer 2010). Previous studies have proved the usefulness of TLS and ALS in mapping the micro-topography of landscape for the calibration of geophysical data (Neubauer *et al.* 2012), and the integration of these different prospection methods has the long term potential to enable more effective heritage management (Doneus *et al.* 2007). The introduction of MMS adds a further tool to the surveyor's toolkit, and has the potential to provide rapid and accurate survey of archaeological landscapes.

3.3 The Nature of Terrestrial Laser Scanning Data

The variety of terrestrial laser scanning system used in any given survey plays a large role in determining the general characteristics of the resultant data (Hetherington 2009). However, the principle output of all laser scanning technology is measurements in the form of x, y, and z coordinates. This dense collection of three-dimensional measurements is referred to as a 'point cloud' (See Figure 35 below).

In addition to x, y, z coordinates, most TLS systems also record the strength of response of the laser's reflection from a surface and assign it a value between 0 and 1. This value is referred to as the 'intensity return' and varies dependent on a number of factors, principally range, colour and surface characteristics of material and angle of incidence of the laser signal. The intensity return is preserved by the scanner as it can be used to differentiate between surface materials, and is an important visual aid in the analysis of the resulting data set (See Figure 35 below). In terrestrial laser scanning this is often used to help distinguish edges of features for the creation of CAD based models, but some attempt has been made to use these responses to detect differences in near surface conditions, in much the same way as it has been applied in airborne

Figure 35 – Point cloud created from the terrestrial laser scanning survey of the Old Royal Naval College in Greenwich. Each point represents an *x, y, z* measurement, with the colours representing the strength of intensity returns reflecting from differing surface materials.

laser scanning. Time-of-flight terrestrial laser scanners also have an inbuilt camera, which is aligned with the internal mirror, allowing RGB colour information to be mapped over the *X, Y, Z* measurements, colouring the point cloud (See Figure 36 below).

Figure 36 – Results of the terrestrial laser scanning survey of the site at Low Hauxley (see Chapter 8 below), with RGB colour values taken from the internal camera mapped over the point cloud.

Measurements taken by all forms of terrestrial laser scanner are initially recorded in an arbitrary coordinate system relative to the scanner with the point of origin (0,0,0) being set at the point of laser emission. The datasets then have to undergo a process known as 'registration' in order to transform the data from the arbitrary coordinate system to a known coordinate system, such as that of a local mapping frame (Lichti and Skaloud 2010). This registration of data enables multiple point clouds to be placed within the same coordinate system to build a much larger data set. Scans from different positions are linked by means of common targets placed over control points in the field of view of the scanner within both scans. The software then detects these targets and uses them as reference points to link the datasets together. Ideally five or more targets are used, and are spaced as widely as possible to maximise the accuracy of the registration (Charlton *et al.* 2009).

For most processing purposes, terrestrial laser scanning data is preserved in the form of a point cloud, which can be outputted and stored in a simple ASCII format (See Figure 37 below). While point clouds are the standard output of laser scan survey they are rarely used as an end product, and are instead used to form the basis of a secondary level of processing, although as will be seen in Chapter 8, the ability to use the point cloud itself for analysis is rapidly developing. A common application of terrestrial laser scanning is the creation of measured drawings similar to those created by total station or GNSS survey by tracing two-dimensional drawings from the three-dimensional data contained in the point cloud. This has been employed mainly within industries used to interpreting and presenting two-dimensional survey data, such as architecture and archaeology. More scientific analysis of terrestrial laser scanning data involves transforming a point cloud into a solid surface, usually through the process of 'meshing', which uses adjacent points in the data set to form triangles and create a solid surface model. Due to the complexity of creating a mesh and the sheer scale of the data processing involved solid surface modelling is rarely done as a matter of course, and TLS data is usually stored and archived in point cloud form.

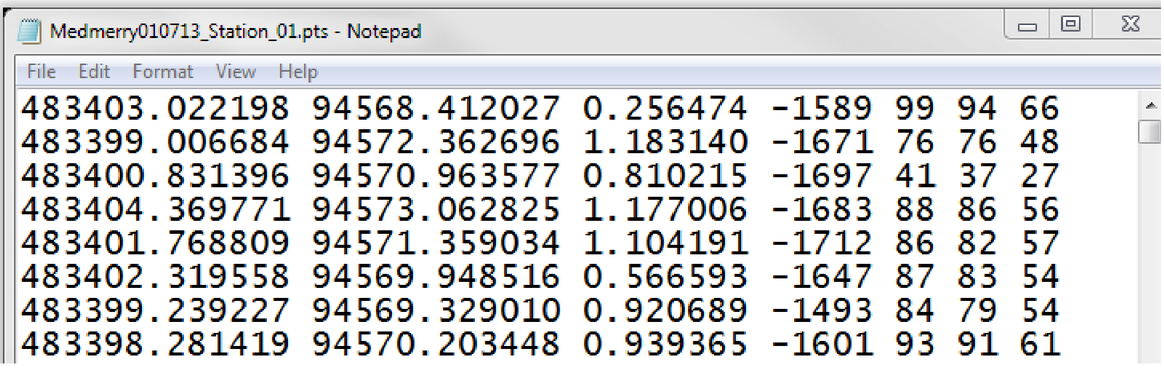
Medmerry010713_Station_01.pts - Notepad
File Edit Format View Help
483403.022198 94568.412027 0.256474 -1589 99 94 66
483399.006684 94572.362696 1.183140 -1671 76 76 48
483400.831396 94570.963577 0.810215 -1697 41 37 27
483404.369771 94573.062825 1.177006 -1683 88 86 56
483401.768809 94571.359034 1.104191 -1712 86 82 57
483402.319558 94569.948516 0.566593 -1647 87 83 54
483399.239227 94569.329010 0.920689 -1493 84 79 54
483398.281419 94570.203448 0.939365 -1601 93 91 61

Figure 37 – An example of the .pts ASCII file format opened in a simple text editor. The columns from left to right represent *x*, *y*, *z*, intensity return, and R, G, B colour values

3.4 The Limitations of Terrestrial Laser Scanning

Laser scanning technology follows the principles of trigonometric surveying. In essence, the technology works by calculating the angle and distance from a known fixed point to the point being measured. As the measurement is taken by a pulse-echo laser, it operates on a line of sight principle, what cannot be seen, cannot be measured. Inevitably this leads to blind spots within the data (Grussenmeyer *et al.* 2008) or 'shadows'. These voids in the data can be filled during the registration process by adding data from other scanning positions, but in the case of terrestrial laser scanning it is quite common for areas on complex objects or structures to be immensurable using laser scanning equipment. In these cases, additional survey techniques are required to fill in the gaps.

Terrestrial laser scanners are considered highly accurate compared to other forms of survey technology, however, a number of factors can lead to a reduction in overall accuracy. The registration process inevitably leads to a much greater level of cumulative error in amalgamated data sets than in data gathered from one static position. It is essential, therefore, that the 'accuracy' of a survey is measured as the accuracy of the completed dataset as a whole, rather than the accuracy of measurement from a single setup.

The reflectivity of a target has an impact both on the range of the scanner and on the material that can be recorded. The reflectivity of a material is dependent on its colour and surface condition and can range from close to 0% for dark, matt surfaces, to nearly 100% for bright glossy surfaces. Although targets with a reflective value close to 0% are naturally non-responsive, materials at either end of the spectrum are not easily recorded, and highly reflective metal or water can have reduced or no measurements (Charlton *et al.* 2009). Materials that reflect poorly cannot be measured well at distance (Petrie and Toth 2009b), impacting on the range of the scanning equipment. The reflectivity of different types of laser should also be taken into consideration. San José Alonso *et al.* (2011) compared models of terrestrial laser scanner, and found that the data gathered by a phase-based terrestrial laser scanner was affected by the translucency of the material scanned, whilst the time-of-flight terrestrial laser scanner had no such issues.

The angle of incidence also has an impact on the data collected. When a laser hits a tilted surface the footprint of the laser spot is stretched, causing the return echo to have an elliptical shape (Beraldin *et al.* 2010). Similarly, the overlap of the footprint of the laser beam on the edge of an object (whilst advantageous for airborne laser scanning as it enables the penetration of vegetation) creates difficulties in terrestrial laser scanning as it effects the ability of the equipment to accurately record the very edge of an object. As the footprint of the laser spot increases with range and angle of incidence, the effect of these variables likewise increases.

Atmospheric conditions have a strong influence on the usability and functionality of terrestrial laser scanning. Ambient light can have an impact with strong sunlight reducing the ability of the scanner to record data. Additionally, all forms of precipitation, such as fog, rain or snow, can create a 'backscatter' effect, leading to noise within the resultant data set (Charlton *et al.* 2009). Standing water is likewise a significant problem, and in general terrestrial laser scanning is not attempted through water, however recent use of green-wavelength terrestrial laser scanner to penetrate shallow water up to a depth of 0.7m (Miura and Asano 2013) has shown positive results, although this process requires significant correction of the raw data.

Alongside problems inherent in the technology, operational issues further complicate the use of terrestrial laser scanning. Chief amongst these is the prohibitive cost of the equipment, which is much greater than that of comparative technologies (Large and Heritage 2009). All forms of laser scanning technology are comparatively expensive, and as well as the initial outlay for equipment, the collected data requires the development of specific expertise in post-processing (Charlton *et al.* 2009). This prohibitive cost explains in part the much slower adoption of TLS compared with that of ALS, as professional terrestrial surveying is most often carried out by individual practitioners or small local partnerships (Petrie and Toth 2009c). By comparison ALS data has chiefly been collected by much larger bodies such as the Environment Agency, and the data resold or reused, reducing the cost burden. This is rarely possible in terrestrial laser scanning, not merely because of issues surrounding copyright, but also because there are several different scales at which data can be collected, meaning that data collected for one purpose is not directly applicable to another.

Further problems are caused by the scale of data collected by the scanners. Unlike more traditional forms of survey, where the recorded points are subjectively selected by the operator, laser scanners acquire a more objective spread of measurements in a 'point cloud' (Hetherington 2009). The volume of data collected by this method is by comparison colossal, the objective nature of the data collected meaning that the average number of measured points in a survey can be in the tens of millions. The large size of the data necessitates a requirement for large computing power, both for processing and for storage of the digital archive. Long-term storage of digital data is in itself inherently problematic. Data formats, storage media, software and hardware all have a short span and are at continual risk of becoming obsolete (Paquet and Viktor 2005). The lack of consistent standards of data storage within laser scanning means that each brand of scanner usually has its own data format, most of which are proprietary. This leads to an even greater danger to the long term survival of the data (Paquet and Viktor 2005), and there is a necessity of migrating data over time, to update the file formats to the latest versions.

The level of expertise needed within laser scanning has also been problematic in the development of the discipline. The ease of operation of the equipment in the field means that it has the least standardised control practices and error assessments of all survey technologies (Lichti and Skaloud 2010). This is due to the relative infancy of the technology and the apparently complete output it provides (Large and Heritage 2009). Indeed the danger of perceiving the 'point cloud as product' instead of a means of producing well informed and communicative survey drawings or models has been one of the major criticisms of its usage (Blake 2010). At the other end of the spectrum, however, are surveys which subsample or reduce a 3D model to a more traditional 2D drawing due to a lack of knowledge of the medium and its potential (Remondino 2011). The process of representing a 3D landscape, site or object in 2D is well established within metric survey, however 3D models provide much less restriction in the display and analysis of the dataset (Alby and Grussenmeyer 2012). In all sectors that employ laser scanning there is still a lack of clarity regarding where the balance lies between level of detail and usability. This balance is in part defined by the need for ease of manipulation in a virtual product, the ability and capacity of end user to interact with and understand the data, and the outputs required from the collected data set. Within archaeology, there is a tendency to accumulate as much information as possible, and therefore a reluctance to decimate measured data to a standard level. In any survey the key parameters are the size and complexity of the subject and the level of accuracy required in its recording (Grussenmeyer *et al.* 2008). The ability of laser scanning to record vast quantities of data very often means that the required outputs of the survey are only thought of after the data has been collected, very often rendering most of the collected data redundant. However, the ability to provide different levels of data means that structures can be presented at a high resolution for digital documentation but also at a low resolution for dissemination (Lo Brutto and Spera 2011).

3.5 The Application of Terrestrial Laser Scanning to Cultural Heritage and Archaeology

Internationally, CIPA (Comité Internationale de Photogrammétrie Architecturale), a collaboration between ICOMOS (International Council on Monuments and Sites) and ISPRS (International Society for Photogrammetry and Remote Sensing), have hosted a range of conferences and groups dedicated to the study of the application of all forms of laser scanning within heritage since the early 2000s, and have provided a forum for debate on the merits of the technology.

In the United Kingdom, the establishment of the Heritage3D project, a collaborative project between English Heritage and various commercial and academic establishments that used laser scanning reflected the growing use of laser scanning within the heritage sector in the early 2000s. The project was designed as a complement to English Heritage's Metric Survey Specifications, which provided guidance on 'best practice' within Metric Survey (Barber *et al.* 2003). 2005 saw the launch of the Heritage3D website, which reported on existing trials of technology and provided professional guidance in the use of laser scanning for Heritage (Barber *et al.* 2005). By 2007 the first edition of '3D Laser Scanning for Heritage' was produced and the continuity of the project saw a second edition published by 2011 (Mills and Andrews 2011). The emergence of ALS as a distinctive field within heritage laser scanning was reflected in the publication of a separate English Heritage guidance document, *The Light Fantastic* (Crutchley and Crow 2009) prior to the release of the 2nd edition. This distinction reflects the much greater acceptance and usage of ALS by the archaeological community. The Archaeological Data Service, who provide guidance on the long term storage of digital data, has issued policy based on English Heritage guidelines (Payne 2014), which expands the guidance on the vast range of deliverables available from post-processing, and their long term curation. Independent policy on laser scanning best practice and archiving has also been made available through the work of CyArk. CyArk is an independent charity founded in 2003 by Ben Kacyra, an engineer instrumental in the development of laser scanning, whose company, Cyra Technologies produced the Leica 2400, 2500 and 3000 terrestrial laser scanners. CyArk operates with the mission of "Preserving Cultural Heritage Sites through collecting, archiving, and providing open access to heritage data created through laser scanning, digital modelling, and other state-of-the-art technologies" (CyArk 2014) and has been a valuable repository for laser scanning data from internationally important heritage sites.

3.5.1 Terrestrial Laser Scanning in Archaeology

As with all emerging technologies, terrestrial laser scanning was rapidly trialled and appropriated by the heritage sector at a very early stage, and soon hailed as 'a valuable new method for cultural heritage recording and one which will complement and, in certain applications, replace currently existing methods' (Boehler *et al.* 2002). From its introduction terrestrial laser scanning has seen extensive use in the recording of built heritage (Shih *et al.* 2009), archaeological monuments (El-Hakim *et al.* 2004) and within archaeological excavation (e.g. Tucci *et al.* 2011). However, a number of factors has hampered the adoption of terrestrial laser scanning as a standard tool within archaeology. Archaeology suffers from the same problems as all other industries in that cost, expertise and application are very often prohibitive. The financial constraint within archaeology has led to extensive collaboration with external agencies, meaning that laser scanning recording and survey for heritage has often been collected by non-archaeologists, impacting on the focus and thereby quality of the resultant data. Additionally, archaeology is traditionally subjective rather than objective in its recording methods, with the focus being on understanding sites rather than fully recording them. Archaeology is therefore reliant on interpretive drawings and plans rather than the objectivity of a point cloud (Blake 2010). The perceived danger of high-resolution recording has been that of 'documentation for the sake of it' which is seen to impact negatively on the resources available for a project (Andrews *et al.* 2007). Large-scale data collection is, however, of tremendous benefit within archaeology. The continual threat of destruction of sites by cultural or natural means raises the necessity of having a precise, accurate and faithful 3D model of heritage assets (Paquet and Viktor 2005). High-resolution virtual models can also allow the monitoring of degradation over time (Lobb *et al.* 2010) and provide remote access to an object or site via a virtual copy (Paquet and Viktor 2005).

More recent developments have allowed greater fusion between data from a variety of sources. Fabris *et al.* (2012) used a combination of TLS, photogrammetry and traditional survey techniques for a fuller, better textured model of archaeological sites. The integration of the different technologies has been shown to result in 3-dimensional models that are of both a high accuracy as well as a high texture resolution (Gašparović and Malarić 2012). The use of terrestrial laser scanning in providing photo-real virtual models has proved of great use in communicating the historic environment to the wider public, from simple site presentations to the ability to illustrate the effects of climate change on the historic environment (Nettley *et al.* 2011). However, the use of terrestrial laser scanning in archaeology has gone beyond simple digital documentation of heritage, and is a valuable tool in creating accurate baseline records for long-term monitoring of sites and monuments such as the Moai of Easter Island (Kersten *et al.* 2009). The recent Scottish Ten project, co-ordinated by Historic Scotland, has sought not only to record sites such as Skara Brae using TLS, but has installed permanent survey markers so that repeat scans will have the ability to inform on the impact of coastal erosion on the monument (Wilson *et al.* 2011). The high-resolution spatial data provided by terrestrial laser scanning provides a highly detailed micro-topography upon which to map other forms of data. Cabrelles *et al.* (2009) have used image data gathered from thermography to map the effects of water damage on historic monuments within the Petra World Heritage Site, informing the long-term strategy for the monument's conservation. TLS, therefore, has proved not only to be a valuable tool in the recording of cultural heritage but also in its long term monitoring and conservation.

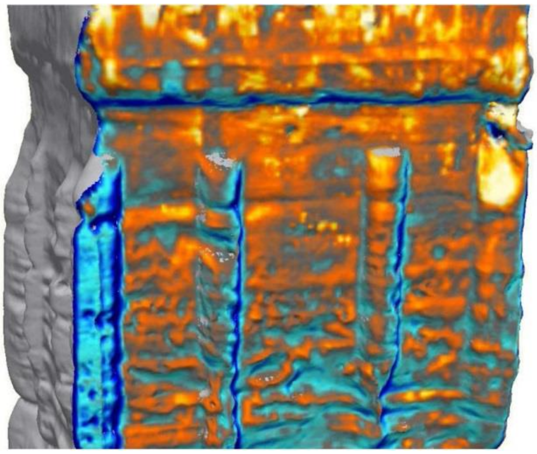

Figure 38 - Thermal infrared imagery mapped over terrestrial laser scanning data in order to detect erosion in monuments at the World Heritage Site at Petra, Jordan (Cabrelles *et al.* 2009)

Recent projects within wetland archaeology have seen the application of TLS to wet preserved wooden structures including an Iron Age post alignment at Geldeston, Norfolk, *in situ* wooden remains at Star Carr, North Yorkshire and Bronze Age fishweirs at Must Farm, Cambridgeshire (Krawiec 2012*, pers. comm.*). Within the intertidal zone, projects in the Shannon and Fergus estuaries in Ireland have seen the application of TLS to the recording of archaeology, specifically that of fishweirs (Shaw and Devlin 2010). Here the technology was used for detailed recording within a challenging environment, with the results providing visualisation of the data in point cloud form and translation of the structures metrics into a wider GIS context.

3.6 A Proposed Methodology for Recording Intertidal Archaeology Sites using Terrestrial Laser Scanning

Any approach to the recording of intertidal archaeology must seek to place it within its immediate landscape; therefore, any survey-based approach must use a technology that can accurately and efficiently link archaeological features and structure with both its immediate and wide-scale topography. An underlying principle of archaeological policy is that:

"the protection of the archaeological heritage must be based upon the fullest possible knowledge of its extent and nature. Good survey of archaeological resources is therefore an essential working tool in developing strategies for the protection of the archaeological heritage. Consequently archaeological survey should be a basic obligation in the protection and management of the archaeological heritage" (ICOMOS 2004, p105)

and in particular that this is of a high priority

"when total or partial demolition, destruction, abandonment or relocation is contemplated, or when the heritage is at risk of damage from human or natural external forces" (ICOMOS 2004, p131)

Archaeological excavation is by its very nature destructive. The debate over the merits of archaeological excavation as a means of adding to our knowledge of the past (or 'preservation by record'), versus the value of retaining such deposits for future investigation (or 'preservation *in situ*') has been much debated within the discipline. In the case of sites threatened by coastal change in the form of erosion (rather than those being lost by deposition), the option of preservation *in situ* does not exist. In this event, the fullest possible record of a site should be made. The dynamic nature of the intertidal environment not only poses a threat to the archaeology in the form of erosion, but also presents very real challenges to fieldwork and survey. Terrestrial laser scanning has the ability to deal with all of these challenges.

3.6.1 Best Practice and Site Methodology

The use of terrestrial laser scanning in archaeology, and in particular wetland archaeology, has slowly begun to increase over the past few years. Whilst general guidelines on technical issues such as data management have been provided for terrestrial laser scanning (e.g. Mills and Andrews 2011, Payne 2014), as yet little has been done to establish 'best practice' in the use of terrestrial laser scanning in fieldwork. The additional challenges of the intertidal zone mean that, whilst each site requires an individual approach to survey, general guidelines for the survey of intertidal sites must be established with regards to the use of terrestrial laser scanning. The following sections outline a general best practice, the application of which will be reviewed in the conclusions at the end of this work (Chapter 9).

3.6.2 Technical Setup

Terrestrial laser scanning works on the basis of **line of sight**, what cannot be directly seen by the scanner will not be recorded. The positioning of any field setup will therefore produce voids or 'shadows' in the data behind objects forming areas within the point cloud with no recorded returns (Figure 39).

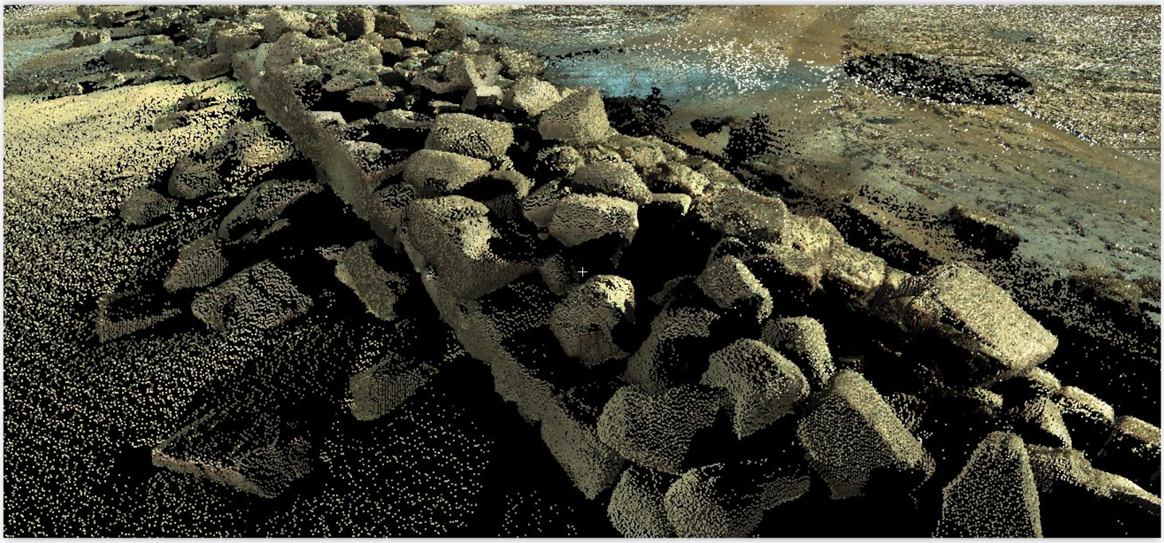

Figure 39 - Terrestrial laser scanning data of the structure at le Yaudet (see Chapter 5). The 'shadows' behind the rocks are voids in the data caused by a lack of survey coverage.

These 'shadows' are eliminated by setting up the scanner in numerous positions to fill in the gaps in the data. However, additional setups require additional time, so a good survey strategy will aim to minimise the number of setups in a survey while collecting the maximum amount of data. Additional moving barriers such as traffic, cattle and especially people can also interfere with data collection. The **distance** from the equipment to the target has a bearing both on the spacing of points and on the accuracy of the data gathered; with both values decreasing the further a target is from the scanner. Likewise, the **angle of incidence** between the laser and its target can affect the resolution and accuracy of the data, with the footprint of the laser spot increasing as the angle of incidence becomes more oblique. **Reflective** or transparent surfaces such as water or glass can give inaccurate or negative responses, with large amounts of standing water or rain creating noise in the data. The **stability** of the equipment also has a bearing on the quality of the data, with most scanners having an automatic shut off if too high a degree of instability is detected.

An ideal setup, will aim to minimise the amount of voids within the data, whilst maintaining an appropriate distance from the target at as non-oblique an angle as possible.

3.6.3 Data Collection Choices

Whilst many have perceived terrestrial laser scanning as an objective method of recording, some subjective elements remain, with the choice of setup, resolution, and indeed the decision to survey at all being conscious decisions made prior to or during survey. It can more realistically be described as a less subjective recording method, but one that still requires a degree of choice in the manner of data collection. Once the technical setup of the equipment is complete, a number of factors need to be considered in the collection of data. The most significant of these factors is **resolution**. The specific research aims of the survey, as well as the scale of the site or landscape being surveyed will dictate the spacing of the points. Hand in hand with the setting of resolution should come an understanding of **accuracy.** This applies not only to the accuracy of the terrestrial laser scanner at each setup location, but the overall accuracy of the survey once completed, including the effects of using additional equipment such as GNSS or total station to register or georeference the datasets. Thought also needs to be given to the **registration** of data, the means by which individual setups are linked together to form a complete survey. How closely this can be achieved affects the overall accuracy of the dataset, the full survey can be let down by a poor registration between the individual point clouds. Two principal methods of registration exist, the use of registration targets or 'cloud to cloud' registration that involves picking matching points within the datasets post-collection. Registration targets provide a more accurate registration but require longer to set up and record in the field, whilst the 'cloud to cloud' approach takes more time post-collection to process. G**eoreferencing** of the data is also crucial, in order to establish its position within a mapping frame, and to accurately place it in terms of elevation. This can involve the use of GNSS, or total station survey to relate the survey to local benchmark positions. Repeat surveys should involve permanent ground control established on site to remove the potential inaccuracies caused by the use of GNSS.

Archaeology sites and structures within the coastal zone should be recorded at a resolution that futureproofs against site loss, capturing enough detail to produce measured drawings of the site, and provide a full record of its immediate topography, with a point spacing of ≤4mm. In accordance with best practice, the overall survey should aim to have an overall cumulative RMS error of less than 20mm. Individual setups should be linked together using registration targets positioned over control points, which can then be georeferenced by recording their position using GNSS. Where repeat visits to sites are required, these control points should consist of permanent ground control.

3.6.4 Logistical Deployment

The amount of **time** taken to record sites is one of the most limiting factors in any survey. Not only must the time required for the scanner to collect data in each setup be taken into account, but also the time taken to reposition the scanner between individual setups as well as the unloading, setting up and breaking down of the kit at the end of the survey. The **distance** travelled to the site can not only lead to an increase in the time taken for the survey, but also have a bearing on the amount of people needed to transport the equipment. Remote sites in fringe landscapes such as the coastal zone are often inaccessible by road, so thought must be given to how equipment and personnel will reach the site. All archaeological site work is limited by **environmental factors** and in particular the weather. Strong winds can affect stability of the equipment, and are particularly of note in open landscapes with little cover such as hilltops, fens and estuaries. Precipitation such as rain or fog can lead to a reduction in the quality of data collected, whilst extremes of temperature can cause the equipment to stop working. Daylight is less of an issue than with image-based modelling, but ambient light can still have an effect on the quality of the data captured, not least in the inability of the scanner to capture colour information. All of these factors affect not only the scanner but also the operator as well (a frequently overlooked but extremely important part of the survey equipment) and reduction in the safety, health and comfort of the operator leads to a similar reduction in the quality of the data gathered. **Additional survey kit** such as GNSS or total stations may be required to link the terrestrial laser scanning survey to the national grid or chosen mapping frame. It is best practice in any survey to collect additional information as **metadata** for the survey. This typically includes written notes detailing information such as time, date, weather, personnel, project file names and equipment settings. Sketch plans and witness shots showing setups and target locations should also be recorded and stored as part of the survey metadata. It is also good practice to note the rationale for the choice of setup, resolution and so on, as these have a bearing on the eventual quality and usefulness of the data.

3.6.5 Post-Fieldwork Processing

Once the dataset has been registered and georeferenced within the software, the cumulative RMS error of the registration should be noted to establish the overall accuracy of the survey. **Cleaning** of dataset can then be carried out to remove extraneous points or noise, caused by moving obstacles such as people and erroneous data caused by refraction or reflection. **Archiving** of the dataset including all metadata should occur as soon as these initial steps have taken place. The archived data should be saved in an open access or non-proprietary file format that permits long-term accessibility of the data and allows it to be used in a wide range of software. **Documentation** of all stages of post-processing should also be recorded and stored with the final archived dataset.

3.6.6 Challenges of the Intertidal Environment

Unique challenges exist in the survey of sites within the intertidal zone. The most significant of these is guaranteeing the **safety** of the personnel and equipment involved. This involves not only a clear and well thought out risk assessment, but also relies heavily on **local knowledge** of tides, currents and ground conditions. Standard risk assessment templates were provided by

English Heritage in advance of the Rapid Coastal Zone Assessment Surveys (English Heritage 2007), and provide a good outline of the risks associated with working in the coastal and intertidal environment. The **timing** of surveys in such environments is much more challenging than in other landscapes, as time on site is not only limited by tides, but also further restricted by when appropriate tides coincide with other environmental factors such as daylight hours and seasonal weather patterns. **Subsidence** of the ground surface, which has a negative effect on the stability of the equipment, is likewise more challenging in the intertidal zone, which is frequently composed of soft sediments, and in addition has a rapidly changing water table that can alter the stability of the equipment over the course of a survey. **Vegetation** and debris, such as seaweeds and nets can obscure archaeological remains, which often form the most solid and prominent features on the foreshore.

The survey of coastal and intertidal archaeology sites requires additional planning to terrestrial survey due to the challenging nature of the environment. Fieldwork should aim for times of the year when vegetation is at a minimum. At least one visit to site should occur prior to the planned survey to assess the specific risks of the terrain. Tide tables and weather forecasts should be consulted prior to each day's work and local advice sought about the nature of the environment.

3.6.7 Approach Used Within This Thesis

The next five chapters represent individual case studies designed to test the use of terrestrial laser scanning in coastal and intertidal archaeology. In applying the above best practice, the following should be noted. Firstly, whilst some of the sites were deliberately chosen as test grounds for new techniques (Chapters 4 & 6), the remainder consist of sites where ongoing research excavations permitted an opportunity to apply the techniques to existing archaeological workflows. In these cases the methodology was reactive rather than proactive, responding to the nature of the archaeology as it was uncovered. Rather than being a negative, this better represents the nature of archaeological excavation, and tests the rigour of the proposed methodology. In addition, the site at Low Hauxley (Chapter 8) had an additional variable in the form of significant coastal erosion, which provided a further challenge to the methodology.

Secondly, the nature of survey was to some degree dictated by the equipment available. In each case study the surveys were carried out using a Leica ScanStation C10 scanner. The C10 is a time-of-flight terrestrial laser scanner capable of a range of up to 300 m, although a working range of 100-150 m is more typically assumed. The scanner is capable of recording points at a spacing of up to 1 mm, and has a field-of-view of 360° on the horizontal axis and 270° on the vertical axis. Whilst the equipment itself did not restrict work on site (being at the time of survey one of the most recent models of scanner) thought should be given in all surveys to the choice of equipment used and its positive and negative characteristics. Furthermore, consistent use of the same piece of equipment is essential in repeat survey of sites, as it minimises the differences in the data than can arise from using multiple pieces of kit.

3.6.8 Placing Sites within the Tidal Frame

Terrestrial mapping requires reference to a base datum, an arbitrary point of 0m, referred to as sea level. Within the mainland UK, the datum used for terrestrial mapping is Ordnance Datum Newlyn (ODN) and refers to the mean sea level at Newlyn, Cornwall as recorded over the six-year period between 1915 and 1921. Several smaller local datums exist for offshore UK islands such as the Orkneys and Channel Islands. Both Northern Ireland and the Republic of Ireland maintain their own terrestrial mapping datums, Ordnance Datum (Belfast) is based on the mean sea level at Clarendon Dock in Belfast between 1951 and 1956, and Ordnance Datum (Dublin) is based on the lowest tide recorded in Dublin Bay on the 8th April 1837 (UKHO 2014). Several mapping projections exist in mainland France so the situation is rather more complicated, but in general IGN69 is used, which uses as a datum the NGF (Nivellement Général de la France) which is taken from the mean sea level at Marseilles (Simon 2013).

Datum	How fixed	Applications	Advantages	Disadvantages
Tide Gauge Benchmark	Local levelling	Single tide gauge reference	Long-term stability; an interconnected group covers for accidental damage	Often damaged; includes vertical land movement
Chart Datum	Tidal analysis and levelling	Navigation charts	Level below which sea seldom falls	Varies with tidal range; unsuitable for numerical modelling
Land survey datum (MSL)	Regional levelling and sea level averaging	Approximate geoid for national mapping	Horizontal surface transferred by levelling	Systematic errors in conventional levelling
Geocentric coordinates	Analysis of satellite orbits	Altimetry, GPS	A geometric framework; detects local movements, e.g. of TGBMs	Small changes as mass e.g. ice, redistributes
Geoid	Satellite orbits and modelling	Ocean circulation	True horizontal surface; absolute level for ocean dynamics	Needs special satellite gravity mission

Table 1 – The characteristics of the various datums used for sea level measurements (from Pugh 2004)

However, within maritime mapping a different vertical constant is used. Chart Datum (CD) is defined by international agreement as a level below which the sea level will not fall, and is used as the vertical datum on both charted depths and tide heights. In both the United Kingdom and France Chart Datum, or zéro hydrographique (ZH) in France, is taken to be the lowest astronomical tide (LAT) as recommended by the IHO (International Hydrographic Organization). As the lowest astronomical tide varies significantly around the coastline, CD is not a universal constant, but instead is calculated for every major port based on long-term observations of the LAT. In order to provide accuracy and long-term maintenance of CD, most major ports maintain tidal gauges that are positioned where they can be referenced to terrestrial benchmarks. Ports with maintained tidal gauges are referred to as Standard Ports, whilst those whose tidal heights are calculated by reference to a Standard Port are known as Secondary Ports.

Site	Standard Port	Secondary Port	Offset of CD to OD at Secondary Port
Aust	Port of Bristol (Avonmouth)	Beachley (Aust)	-6.1m
Léguer	Roscoff	Locquemeau	-4.92m
Emsworth	Chichester Harbour (Entrance)	Northney	-2.74m
Medmerry	Portsmouth	Selsey Bill	-2.90m
Low Hauxley	River Tyne (North Shields)	Amble	-2.65m

Table 2 – The relationship of the various sites used as case studies in this thesis to their closest Standard and Secondary Ports

In order to place an intertidal archaeology site within the modern tidal frame, we must therefore know the offset between the datum used in terrestrial mapping and the Chart Datum used at that point of the coast. For sites in mainland Britain this is quite straightforward, as most are close enough to Standard or Secondary Ports to allow easy reference. For example, at the site of Aust (Chapter 1), the Secondary Port of Beachley (Aust) immediately to the south of the Severn Bridge was used, a distance on only 1.8 kilometres from the site. The offset of Chart Datum at this point is -6.1m relative to ODN, calculated from the Standard Port of Bristol (Avonmouth) only 14 kilometres to the southwest. Due to the relative nature of chart datum and thus tidal levels, it is important that the specific details the chart datum used, and its contemporary estimated relation to ODN, is recorded as part of any investigation of coastal or intertidal sites. Full details of the tidal range at each site are provided in Appendix 1.

3.6.9 Uncertainty in Intertidal Survey

As noted in Section 3.2 each form of survey technology has its own inherent level of accuracy. Accuracy in this case refers to the closeness a recorded measurement in a survey has to its true measurement. The differences between recorded and true measurements are the result of errors. Errors stem from a number of sources, but can be grouped into three categories, systematic errors, gross errors and random errors. Systematic errors, or biases, and gross errors, are mistakes that can be eliminated by having equipment calibrated and checked prior to use, and by using self-checking survey methodologies. Random errors are statistical errors inherent to any form of survey, and are used to quantify the standard error of the equipment. Equipment manufacturers generally provide these as a ±mm value. Uncertainty, or error in accuracy, is inevitable in any survey and is not problematic as long as it is quantified and understood. In general, the degree of accuracy or uncertainty within a survey should be less than the desired resolution, to prevent the uncertainty from invalidating the survey.

Uncertainty varies depending on the type of equipment used for a survey and the integration of different forms of survey. Survey equipment such as total stations of terrestrial laser scanners are often described as accurate to ±2mm, but this reflects a singular measurement on a static plane. The accuracy of the measurement taken by the equipment is not necessarily equal to the accuracy of the internal measuring laser. Rotation of the equipment and the use of multiple setups within a survey adds to the level of inaccuracy and means that the uncertainty within a survey is dependent on the integration of the data into one dataset. Once the accuracy of the equipment, the accuracy of the survey and the accuracy of the total survey (i.e. the integration of various datasets) is known the level of uncertainty can be ascertained. With modern survey, the equipment calculates error and cumulative error so it is possible to provide a measure of the accuracy of the survey with no additional effort. In addition, some survey software use computations and algorithms that correct and improve the overall accuracy of the survey. In terrestrial laser scanning software, this involves identifying overlapping point clouds to provide a further level of control between survey setups.

In order to reduce the uncertainty in a survey to an acceptable level, the first question must be how accurate must the survey be. This will define the level of survey control necessary on site. In the following case studies, ongoing work at Léguer and Low Hauxley meant that return visits to site were necessary. Integration of surveys from there repeat visits, and the comparison of data form multiple visits at Low Hauxley required minimal uncertainty. The use of GNSS at each visit would have significantly increased the uncertainty between surveys. Permanent survey control in the form of nail fixed into the ground minimised the inaccuracy between surveys to allow for a more accurate integration and comparison of data. The choice of equipment and additional controls used is therefore extremely important in quantifying and controlling the level of uncertainty within a survey.

In all cases, the accuracy of the survey, its controls and the resultant level of uncertainty should be recorded and provided as part of the archive. In the following case studies a table is provided outlining the cumulative uncertainty within each survey.

3.6.10 Case Studies

The following five chapters represent a range of coastal sites dating from the prehistoric through to the 20th century, and encompassing a range of site types from palaeoenvironmental deposits to stone built structures (See Table 3 below).

Site name	**Date**	**Landscape context**	**Position in tidal frame**	**Function**
Aust	19th/20th century	Estuarine	High	Fishing structure
Léguer	7th century	Estuarine	Low	Fishing structure/tide mill
Emsworth	19th century	Harbour	Mid-tide	Oyster pits
Selsey Bill	14th century	Reclaimed land	N/A	Unknown
Low Hauxley	Bronze Age	Open coast	High	Burial cairn

Table 3 – Comparative characteristics of sites used as case studies

In addition, the various case studies will discuss the wide range of challenges and opportunities presented in developing terrestrial laser scanning of coastal and intertidal archaeology.

Chapter 4: Integrating Terrestrial Laser Scanning Data with Additional Datasets: An Example from Aust, Severn Estuary

Salmon fishing is of great national importance furnishing a constant and copious source and supply of human food. The fisheries may be said with propriety to rank next to that of the cultivation of land in utilising this intention.

(Rees 1819)

The aim of this chapter is to look at how terrestrial laser scanning can be integrated with various forms of digital information to provide a better understanding of intertidal archaeology sites within wider landscapes, both terrestrial and marine. In particular, this will involve the use of existing topographical datasets, such as airborne laser scanning, bathymetry, orthophotography and Ordnance Survey (O.S.) mapping, and archaeological datasets generated by Gloucestershire County Council Archaeology Services (GCCAS) as part of the Severn Estuary Rapid Coastal Zone Assessment Survey (RCZAS). The structures on the foreshore at Aust in the Severn Estuary, for which a large amount of topographical and archaeological survey data exists, will be used as an exemplar for the integration of terrestrial laser scanning data and as an example of the problems inherent in amalgamating datasets from a range of different sources. The chapter will conclude with an examination of the benefits of integrating different forms of data to complement and enhance terrestrial laser scanning survey of coastal archaeology sites.

The Severn Estuary is an atypical estuarine landscape having one of the highest tidal ranges in the world, second only to the Bay of Fundy in Canada, with a 10-15m tidal range. This extreme tidal range provides both key advantages in the variety of species native to the estuary, as well as unique challenges in the technologies and logistics needed to fish within such an environment. The Severn Estuary could also be argued to be atypical of most coastal areas in the UK in that a large amount of survey data already exists due to its importance as a trade and navigation route, and as a transport link between England and Wales. The narrowing of the river between Aust Cliff and Beachley is known to have been a key crossing point since at least the Roman period, most recently in the form of a ferry service which operated between Aust and Beachley from 1827 until 1966 when it was replaced by the Severn Bridge (Figure 40). The Second Severn Crossing was constructed further to the south at Sudbrook in 1996, prompting extensive archaeological recording of the foreshore (Godbold and Turner 1994). Both of these constructions represent a significant investment in infrastructure showing the importance of cross-river trade and transport between England and Wales. In addition to its importance as a crossing point, the Severn River has a long history as a shipping route, providing transport and trade to significant ports such as Bristol, and inland through the upper reaches of the river and its connection to the canal network.

Figure 40 - Bob Dylan at the Aust Ferry terminal shortly before its closure in 1966 (© Barry Feinstein)

Consequently, there is a large amount of topographical information on the river with detailed mapping of both the terrestrial and marine landscapes, as well as a multitude of historic maps and navigational charts and modern mapping by the Ordnance Survey. More specifically a great deal of remote sensing information exists in the form of bathymetry of the river channel and airborne laser scanning of the coastal zone and alluvial floodplain. Whilst each metric survey was commissioned for a specific purpose, the quantitative nature of the data and the availability of metadata specifying resolution and accuracy mean that there is a strong potential for integration. Each form of survey technology has a different operation methodology in its operation requiring an understanding of the different technologies to ensure that the resultant data is not misinterpreted. Integrating these disparate datasets requires the use of a software package that can read, process and present varying types of data. As with most computer applications in archaeology this is more a case of finding a 'best fit' solution than finding a software package specifically designed for this end. Geographical Information Systems (GIS) software represents the closest fit, although some steps need to be taken to integrate information recorded using terrestrial laser scanning with the other forms of topographical information. The advantage of using GIS software (in this case ArcGIS) is that it has become the standard solution for mapping and analysis of topographical datasets meaning that most existing landscape data is stored in this form and so can be integrated with the three-dimensional surfaces generated from the terrestrial laser scanning.

Figure 41 – Map of the Severn Estuary at Aust/Beachley showing the location of the putcher rank at Aust, Gloucestershire (© 2016 Ordnance Survey (Digimap Licence)).

Being able to visualise the various existing information sets in one software package is central to trying to develop a more holistic approach to the recording of sites at a landscape level. With such an approach we can look to bridge the gap from object, through to site, through to landscape level recording. The use of pre-existing datasets means that significant additional value can be easily added to any basic terrestrial laser scanning survey.

4.1 Salmon Fishing in the Severn Estuary

The foreshore of the Severn Estuary represents one of the densest collections of fixed fishing structures in the United Kingdom, and has a long tradition of archaeological investigation (Jenkins 1974; Dennison 1985; Pannett 1987; Bell 1993; Godbold and Turner 1994). A wide variety of fishing techniques existed within the Severn River and Severn Estuary up to the late

20th century AD ranging from offshore fishing to inshore fishing methods such as drag, trammel and seine netting from boats, through to fixed fishing structures in the intertidal zone to coastal marshland fishing using eel baskets, spears and boxes. The intertidal fixed fishing structures found throughout the estuary are constructed from stone, wood or a combination of the two and comprise a wide range of morphologies from V, W and Z plan forms to complex basketry in the form of putchers and putts (See **Error! Reference source not found.** above). Many of the techniques and practices such as conger eel trapping and putt and putcher fishing are unique to this region, having developed in part due to the unique characteristics of the tidal range and the range of species available throughout the estuary. In particular the Severn Estuary plays host to a large number of migratory fish and has been deemed a SSSI as it contains seven different migratory species (Natural England SSSI listing). These include the European eel (*Anguilla anguilla*), a catadromous species (which spawn in saltwater but live in freshwater) along with a large number of anadromous species (which spawn in freshwater but live in saltwater) including Atlantic salmon (*Salmo salar),* allis shad (*Alosa alosa*), the nationally rare twaite shad (*Alosa fallax)*, the sea trout (*Salmo trutta),* sea lamprey (*Petromyzon marinus)* and the lampern or river lamprey (*Lampetra fluviatilis)*. In addition to the modern anadromous species, as late as the early 20th century the Severn also provided a spawning ground for sturgeon (*Acipenser sturio*) (Figure 42).

Figure 42 – A postcard from the early 1900s showing a fisherman with a sturgeon (*Acipenser sturio)* caught in the Severn Estuary (© Gloucester City Museums)

The parish of Aust on the left bank of the river provides the earliest documentary evidence for fishing in the Severn Estuary dating to c. 690 AD (Rippon 1997), and recent radiocarbon dating of fishing structures in this area has provided an determination of 650-775 cal AD (Chadwick and Catchpole 2013). An Anglo-Saxon charter dating to around 1060 AD from Tidenham, on the right bank of the river opposite Aust describes in detail the requirements for the construction of a weir, and the fate of the fish caught in it, of which certain species were automatically the property of the landowner (Faith 1994; Robertson 2009). Throughout the medieval period stringent restrictions were imposed on the catching of so-called 'royal fish', such as salmon (*Salmo salar*), sturgeon (*Acipenser sturio*) and porpoise (*Phocoena phocoena*) and required that a portion of any such fish caught or its equivalent financial value was given to the landowner (Moore and Moore 1903). As a result, the targeting of such species was of limited advantage, and most of the fishing practices during this period appeared to have been in the form of catch-all techniques such as V-shaped weirs, rather than specifically targeting selected

Figure 43 – Photograph from the 1970s showing fishermen attaching baskets to a putcher rank in the Severn Estuary (© Gloucester City Museums)

species. The exception to the rule was the European eel (*Anguilla anguilla*), whose proliferation throughout the Severn River and Estuary has led to a wide variety of fishing implements and structures designed to catch them. Finds from archaeology excavations within the Severn Estuary have produced archaeoicthyological evidence which implies that fishing for eels was occurring as early as the Mesolithic, most probably with basket traps used in shallow water (Ingrem 2007).

By the post-medieval period some of the restrictions on salmon fishing had been lifted, and development of the railway network meant the ability to ship fresh fish straight to market in populous settlements such as London. This resulted in a significant rise in the pursuit of salmon (*Salmo salar*) within the estuary, leading to the development of both 'putts', large conical baskets of three parts, and 'putchers', smaller baskets fixed in ranks (See **Error! Reference source not found.** above). Both types of trap are unique to the Severn Estuary and its tributaries (Jenkins 1984) and were designed to catch anadromous species, such as salmon (*Salmo salar*) and sea trout (*Salmo trutta)* on a commercial basis (Turner 2005). Putts and putchers operated on both the ebb and the flow tide to trap the fish as it swam forward, forcing it to become caught by its head and drowned by the increased flow of water against its gills (Davis 1958). In general, putts are assumed to be an earlier development than putcher ranks (Godbold and Turner 1994), although historic photos from the 1960s show that both were in use concurrently at this point (Chadwick and Catchpole 2013). The site at Aust is a fine example of a putcher rank, the earliest known examples of which date from the mid-19th century AD (Rippon 1997). A detailed description of the creation and usage of such ranks is provided by Jenkins (1984) who witnessed their construction first hand. The ranks were constructed of two parallel rows of green larch or elm poles up to 15 feet (4.5 m) long, sunk 6 to 8 feet (1.8 - 2.4 m) into the ground. The poles supported large conical baskets constructed from autumn cut willow 'withies' which could be removed from the structure when not is use (See Figure 43 above). By the 1940s the baskets were being constructed from galvanized wire to reduce the labour costs of repairing and replacing them (Jenkins 1984). Ranks were continually rebuilt due to the effects of both tidal forces and rot, at an estimated rate of once every 10 years, although some elm poles are recorded as remaining in place for up to 40 years (Jenkins 1984). A quick visual survey of the structure at Aust shows several phases representing at least eight phases of repair or replacement (Figure 44).

Figure 44 – Various phases of repair and replacement of the structure at Aust, Severn Estuary, shown by the remains of the footings of several posts.

Putcher ranks require a high rise and fall of the tide to allow a profitable number of baskets to be submerged (Jenkins 1991), the baskets were usually stacked three to four high along the full length of the ranks, with some of the larger ranks reported to have had 754 baskets (Chadwick and Catchpole 2013). The geographical confinement of putcher fishing to the Severn, Usk and Wye valleys is due to the fact that the Severn Estuary has one of the highest tidal ranges in the world at around 15m, with only the Bay of Fundy in Canada having a higher range. Putcher ranks are a prime example of a fishing technology that developed within the confines of a specific topographical and socio-economic landscape, and an example of how a note of caution should be raised in direct comparison of fishing structures.

The peak of commercial salmon fishing in the Severn Estuary occurred in the mid-19th century when tens of thousands of the fish were being caught every year. This over-exploitation of the resource, coupled with the effect of pollution, poaching, and canalisation of the waterways significantly depleted the salmon stocks and resulted in the Salmon Fishery Act of 1861 which banned the use of nearly all forms of trap (Turner 2005; Moore and Moore 1903; Bannerman and Jones 1999). Further Acts of 1865 and 1923, were brought in after it was found that salmon had dropped to one tenth or even one hundredth of their numbers within the space of a generation (Turner 2005). However, exception to these laws was permitted by obtaining a government grant or charter, and an allowance was made for the perpetuation of existing structures of 'immemorial use', but no new structures or sites were allowed to be created (Jenkins 1991). As a result the structures which continued in use through the 20th century and into the present day are assumed to be repairs and continuations of earlier sites. Currently only one putcher rank is still in operation at Awre in Gloucestershire. Such sites can then be said to be at risk of loss both materially, and in terms of the cultural practice and understanding of their operation and use.

4.2 Recording the Fishing Structures at Aust

Figure 45 - The putcher rank on the foreshore at Aust, Severn Estuary, photographed at low tide on the 12th March 2013 looking northwest.

A number of approaches have been used in the recording of intertidal fishing structures in the UK (See Section 2.5 above), with the work in the Severn Estuary also having been influenced by the excavations carried out on the Severn Levels Project in the 1970s and 1980s. Since 1985 a number of different excavations and fieldwork have taken place under the umbrella of the Severn Estuary Levels Research Committee (SELRC), which has led to significant amounts of survey of the Severn foreshore, including aerial photography (Allen 2004, Crowther and

Dickson 2008), airborne laser scanning (Brunning and Farr-Cox 2005), field walking (Neumann and Bell 1997; Bell and Neumann 1998) and excavation of specific areas of the intertidal zone (Bell 1993; Bell *et al.* 2000; Rippon 1996; Godbold and Turner 1994). Most recently an English Heritage funded Rapid Coastal Zone Assessment Survey (RCZAS) was completed by archaeologists from Gloucestershire County Council Archaeology Service (GCCAS) (Chadwick and Catchpole 2013). Structures were identified from known written records, as well as from aerial photography and were investigated on the ground by intensive walkover surveys. The surveys recorded the structures using photography, written descriptions and GNSS mapping to create a GIS database of the foreshore (Figure 46).

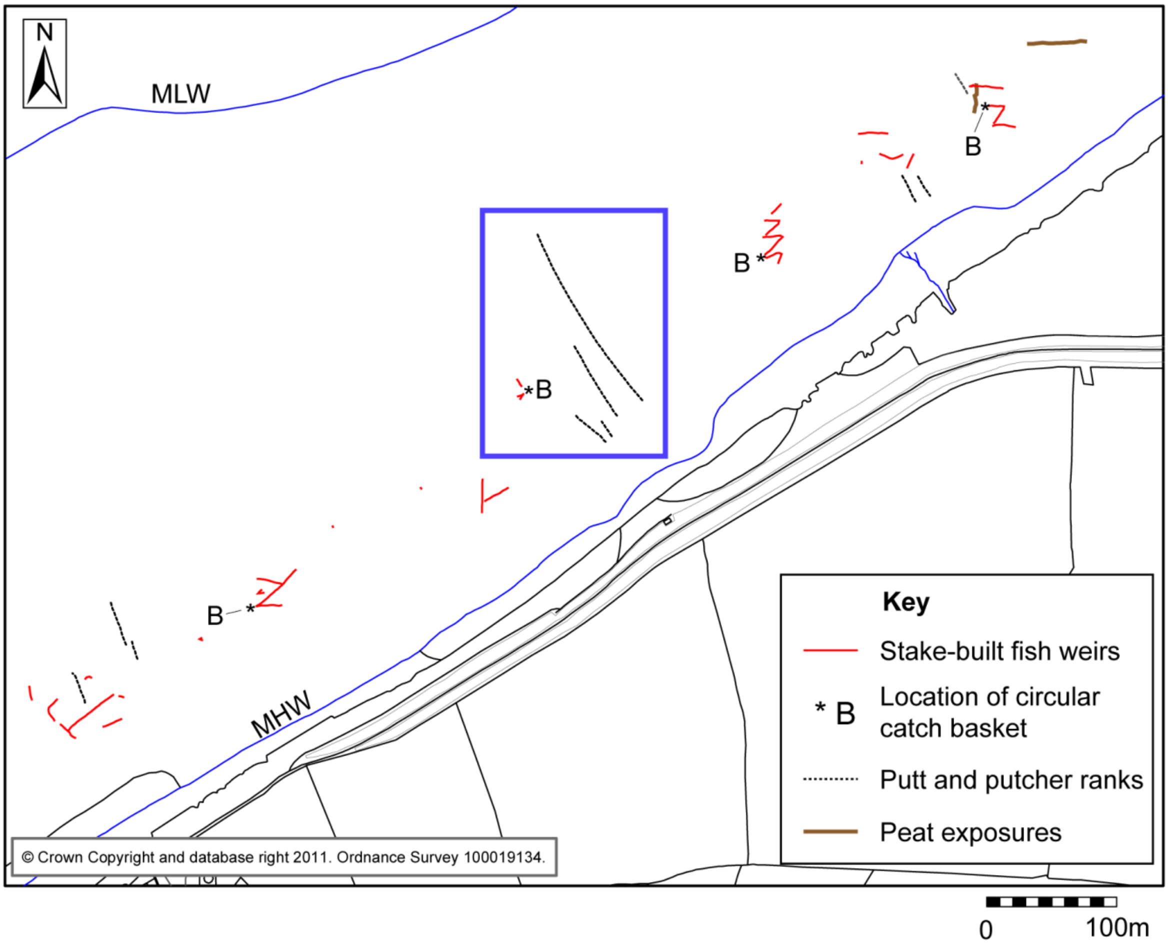

Figure 46 – Map of the intertidal structures on the foreshore at Aust recorded during the RCZAS (Chadwick and Catchpole 2013). The structure recorded using terrestrial laser scanning is within the blue box.

The site at Aust is located on the left bank of the River Severn in Gloucestershire (NGR ST 57732 90614) approximately 1.4 km northeast of Aust Rock (see Figure 41 above), at the upper end of the intertidal zone, and represents a late surviving example of a putcher rank. The foreshore at this point contains a series of fishing structures of which the most prominent is the still extant putcher rank. The foreshore directly surrounding the structure is gently sloping, comprising silts overlying a shingle bank. A number of earlier structures surround the putcher rank, and are presumed to be of medieval and post-medieval date (Figure 46). To the immediate south of the site, a reused railway carriage is positioned on the flood defences with a clear association to the structure, most likely as a store for baskets and equipment.

Equipment Used	**Positional Accuracy**
Leica ScanStation C10 TLS	±6mm
Leica GS09 GNSS	±20mm
Registration Error	±17mm
Cumulative Uncertainty	**±43mm**

Table 4 - Cumulative uncertainty in the survey at Aust

The structure at Aust was chosen as a case study for two reasons. Firstly, the intertidal zone of the Severn Estuary is an extremely dangerous place to work, with sucking muds, rapidly rising waters and strong currents. Some of the intertidal fishing structures within the Estuary are located at a distance of up to 450m from the mean high water spring line, and require the use of boats or all-terrain vehicles to reach. By comparison the Aust putcher rank sits at the high end of the tidal range and is easily accessible from the shoreline, meaning that it is safe to reach on most tides. Secondly, the site is surprisingly extant having been in use until the last decade, and is a prime example of its type rather than a modern reconstruction. In addition, its straightforward morphology meant that it could be easily recorded from a minimum number of positions. Survey therefore comprised a standard terrestrial laser scanning survey of the site, with GNSS providing survey control. The survey was undertaken using a Leica ScanStation C10, which was used to record the structure from four positions. The survey took approximately two hours and gathered 76,208,956 points, at a resolution of ≤3mm. A Leica GS09 GNSS was used to record the position of the registration targets. The resulting dataset was registered in Leica Cyclone software and georeferenced using the GNSS data leading to an overall survey accuracy of ≤13mm. The point cloud was then cleaned and extraneous points removed, in preparation for its integration into ArcGIS.

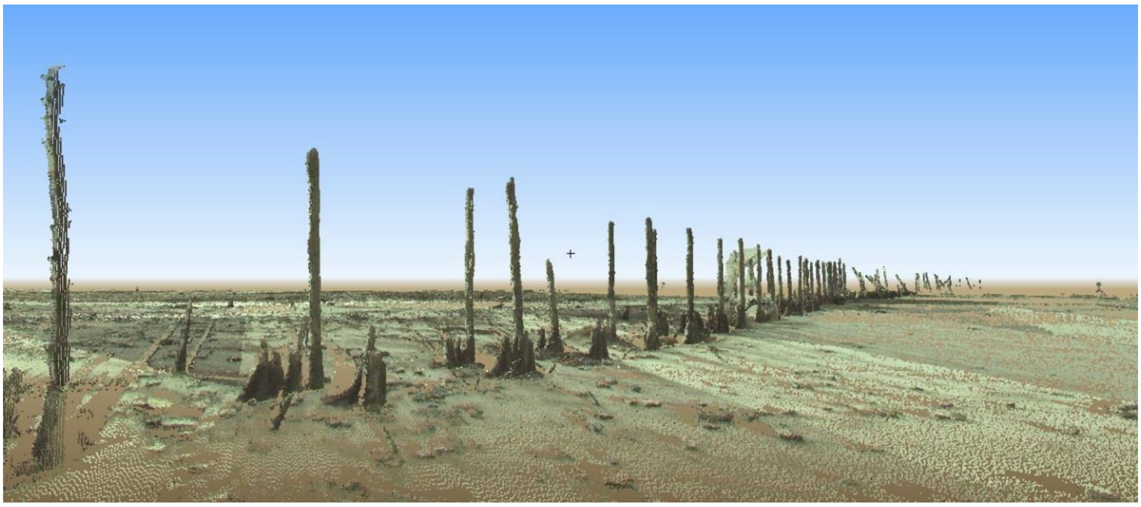

Figure 47 – Results of the terrestrial laser scanning survey of the structure at Aust, Severn Estuary. The RGB values from the internal camera have been draped over the point cloud to create a realistic image of the structure.

4.3 Results and Interpretation

As well as having been the focus of intensive archaeological survey, the Severn Estuary has been well covered by topographic, aerial and bathymetric survey, due to its importance as a major shipping lane and environmental resource. Most of the surveys carried out have been by government departments meaning that the data is readily available for research purposes. The varying forms of data used can be broken down into several general types dependent on the technology used in their capture and its resultant resolution and accuracy (Table 5).

Data Type	Source	Rectification	Accuracy
Metric data	Terrestrial Laser Scanning Airborne Laser Scanning (ALS) Bathymetry	GNSS	±0.2m ±0.4m ±0.5m
Topographic data	Ordnance Survey mapping derived from a number of sources	Various	±1m
Photographic data	Aerial photography False-colour infrared photography (FCIR)	Rectified using ALS	±0.4m
Cultural data	GIS files denoting areas or features possessing archaeological, geographical or legal information	Various	±1m

Table 5 – The type, source and accuracy of readily available data sources of survey in the Severn Estuary

A search of readily available datasets took place using the Channel Coastal Observatory and Digimap websites, both of which provide access to information gathered by the Ordnance Survey (OS), Environment Agency (EA) and United Kingdom Hydrographic Office (UKHO). In addition, the GIS data generated by the Severn Estuary RCZAS was made available by Gloucester County Council for the purposes of this study. Table 6 shows the datasets accessed, their origin, file format and spatial resolution. It is important when integrating such datasets that there is an awareness of the intended purpose of the survey data when commissioned, as it explains the methodology used in its collection and long term curation. The data gathered by the Environment Agency and Channel Coastal Observatory is mainly for the purposes of Shoreline Management Plans and monitoring of coastal changes. The resolution and accuracy of the surveys therefore reflect the need for landscape scale analysis of the coastline. The Severn Estuary RCZAS, commissioned by English Heritage was intended to collate all available information on intertidal and coastal archaeology sites and to quantify and record new sites through a rapid system of field walking. The project stipulated the deposition of all information gathered through the desk based assessment and fieldwork in the form of a GIS database for long term curation and analysis of the data. The features recorded by the RCZAS were accurately positioned using GNSS, but the resolution of individual sites and structures is low, with simple lines or single points denoted an entire feature. The file formats of the surveys again reflect their intended purpose, and are for the most part gridded ASCII or raster files (usually .tiff) for topographical information, with shape files (.shp) containing additional information. The file types are typical of data intended for use in Geographical Information Systems (GIS). GIS is seen as an industry standard in landscape survey and management, as it is the best way to store and compile large scale landscape information. Consequently, the majority of government funded work is made available only in this format. This is problematic as it means that the initial processing of the data has already been carried out, and decisions made on the filtering and gridding of the points. In the majority of cases, the survey work is carried out by private contractors and so the raw datasets are unavailable, and information on accuracy, resolution and precision is unavailable. However, whilst it is not possible to ascertain the specific details of the individual surveys, all conform to standards laid down by the EA and so are within a clearly defined tolerance in terms of accuracy and resolution, in the case of airborne laser scanning having a point spacing of between 1 and 25 points per m^2 and a positional accuracy of $\pm 0.4m$.

All of the data was imported into ArcGIS and converted to a raster format to allow for easier data manipulation. With the exception of the bathymetry data all of the surveys were already in the British National Grid coordinate system, meaning that the datasets could be immediately overlain in ArcGIS. The bathymetry was converted from its coordinate system (WGS84) to the British National Grid coordinate system using standard transformations within ArcGIS. An initial inspection of the datasets revealed a disparity in how the structure was recorded by the various forms of survey. None of the available ALS data (from surveys carried out in 2007, 2009, 2012 and 2014) captured the putcher rank, despite resolutions ranging from 1m to 0.25m point spacing. This may be due to the direction of survey, where the swath has been on a parallel alignment to the structure and so has missed the line, the resolution of the survey, with the structure falling between the spacing of the measured points, or the morphology of the structure, which has a very small surface area on the *X*, *Y* plane. The bathymetry data does not extend up to the high water line and so does not cover the area occupied by the structure. The putcher rank is visible in the aerial photography (which recorded both orthophotography and FCIR photography) and whilst this records an *X*, *Y* position for the structure, it does but not attribute *Z* values to it. Likewise, the RCZAS survey accurately charts its *X*, *Y* position, but the *Z* values relate to the base of the posts, and give no details on the height of the structure. Terrestrial laser scanning, therefore, provides the means to intermediate level of data collection required to visualise the structure in 3D.

Dataset	Source	Format	Resolution
OS Mastermap	OS/Digimap	.shp	N/A
Airborne laser scanning	Channel Coastal Observatory/ Environment Agency	.ascii gridded	1m
Bathymetry	Digimap	.ascii gridded, .shp	1m
Orthophotography	Channel Coastal Observatory	.tiff	N/A
RCZAS data	English Heritage/Gloucestershire C.C.	.shp	N/A
TLS data	Me	.pts, .landXML	≤3mm

Table 6 – Table showing the source and nature of the readily available geographical datasets for Aust, Severn Estuary

GIS based packages are not designed to handle a large amount of point based information, and so point cloud data is not easily transferrable into ArcGIS. The data from the terrestrial laser scanning survey therefore had to be converted into a solid surface model prior to export. In order to accomplish this, the cleaned and registered point cloud was unified into one dataset in Leica Cyclone, and meshed to form a TIN (Triangulate Irregular Network) file. TIN files create basic three-dimensional surfaces by creating a series of triangles between measured points. The simplistic nature of the mesh means that it is usually inappropriate for complex three-dimensional modelling, but was possible in this case due to the largely planar nature of the site, which was in essence a flat land surface with single poles protruding from it. The resulting TIN mesh is by no means perfect in modelling the detail of this site, with the posts resembling elongated cones rather than tubes (Figure 48), but crucial information, such as the maximum heights of the posts above the land surface remains valid.

More complex modelling packages and translations are available, but the conversion of the dataset to a more detailed mesh would create additional difficulties, as ArcGIS is not designed to deal with true three-dimensional data, but rather uses planar extrusion to create a sort of 'two-and-a-half-dimensions'. The TIN mesh was exported from Leica Cyclone as a LandXML file, a non-proprietary file format used in geographic data transfer, and then imported into ArcGIS from LandXML to TIN format. As the dataset was georeferenced prior to export, it immediately sat in the correct location within the GIS.

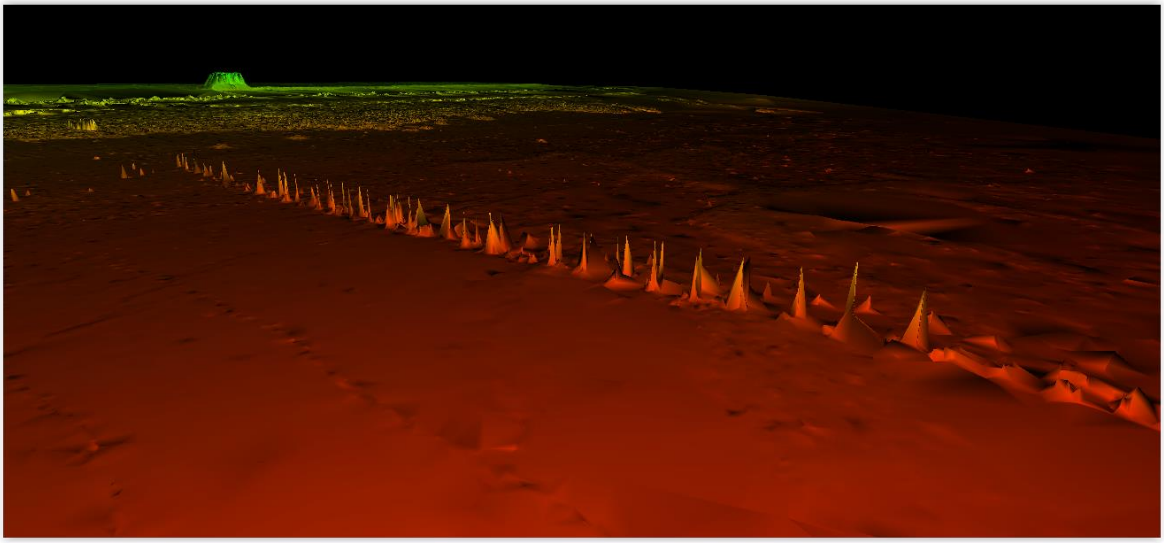

Figure 48 - TIN file generated in Leica Cyclone software from the terrestrial laser scanning survey of the structure at Aust viewed from the north

Once all of the data was converted into formats accessible by ArcGIS two routes of visualising the data where explored. Firstly, overlaying the data in ArcMap allowed for the layering of different datasets in a plan view, whilst importing the data into ArcScene allowed the visualisation of the data in three-dimensions. Comparison of the airborne laser scanning, terrestrial laser scanning, and bathymetry datasets within ArcScene showed that there were significant differences in the elevation values of the different surveys. The elevation values between the airborne and terrestrial laser scanning were only slightly different and could be accounted for by the inaccuracies of *Z* values in both GNSS and ALS survey. A slight vertical offset (0.3m) was therefore applied to the airborne laser scanning data to bring the two dataset to the same level. The bathymetry data was significantly displaced on the vertical axis, being around 8m above the other data sets. This may have been due to the translation from the WGS84 to British National Gird coordinate system, although this is hard to ascertain without the raw data. This displacement raises a note of caution about using metric information from different sources. The bathymetry data was offset to sit at the same level as the laser scanning datasets. Both the OS and RCZAS data was imported and given *Z* values through reference to the airborne laser scanning data. In all cases the *X*, *Y* values needed no correction, and showed a surprisingly strong correlation. The visualisation of data from these various sources immediately highlights the differences in the resolution of the different surveys. A tiling effect is clearly visible in the lower resolution surveys (Figure 51, 52 and 53), leading to the appearance of offshore banks, where the higher levels of detail in the airborne laser scanning survey appear above the averaged heights of the more widely spaced bathymetry data.

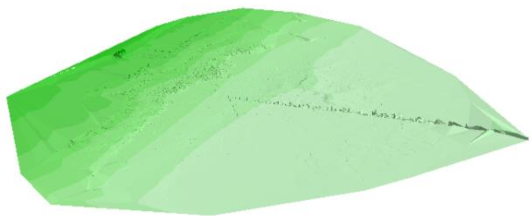

Figure 49 – The terrestrial laser scanning survey of the structure at Aust viewed from the northeast in ArcScene

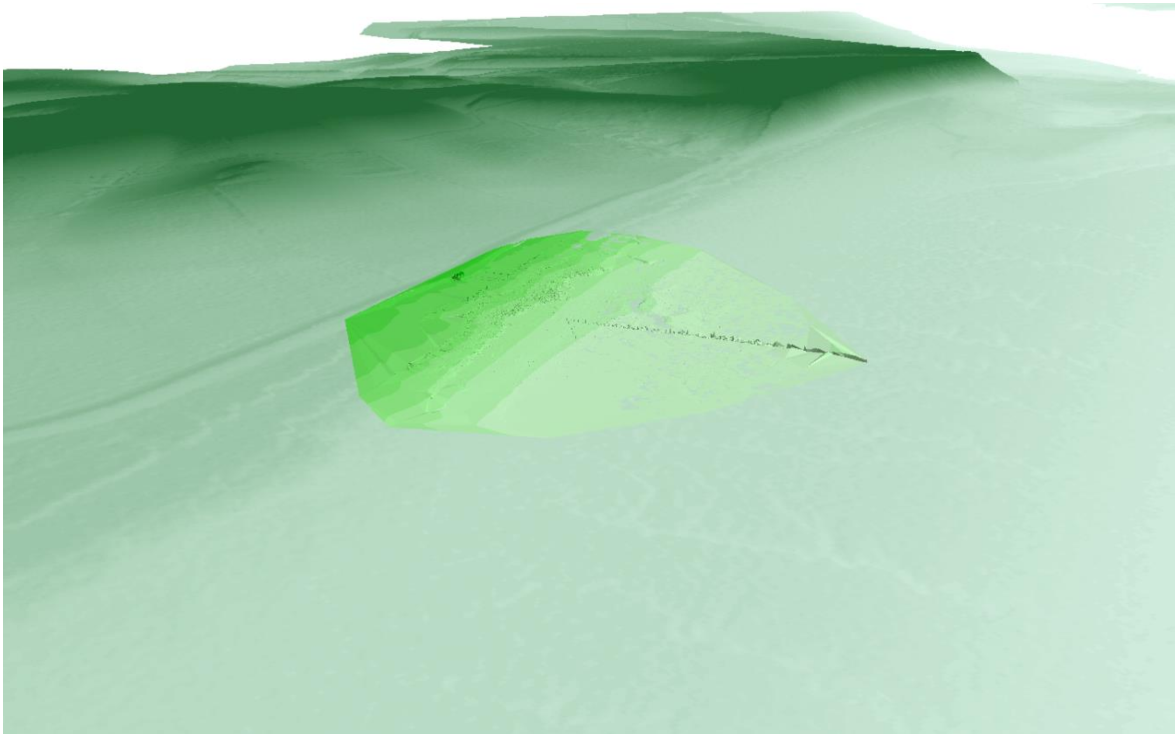

Figure 50 – The combined terrestrial laser scanning survey and airborne laser scanning survey of the structure at Aust viewed from the northeast in ArcScene

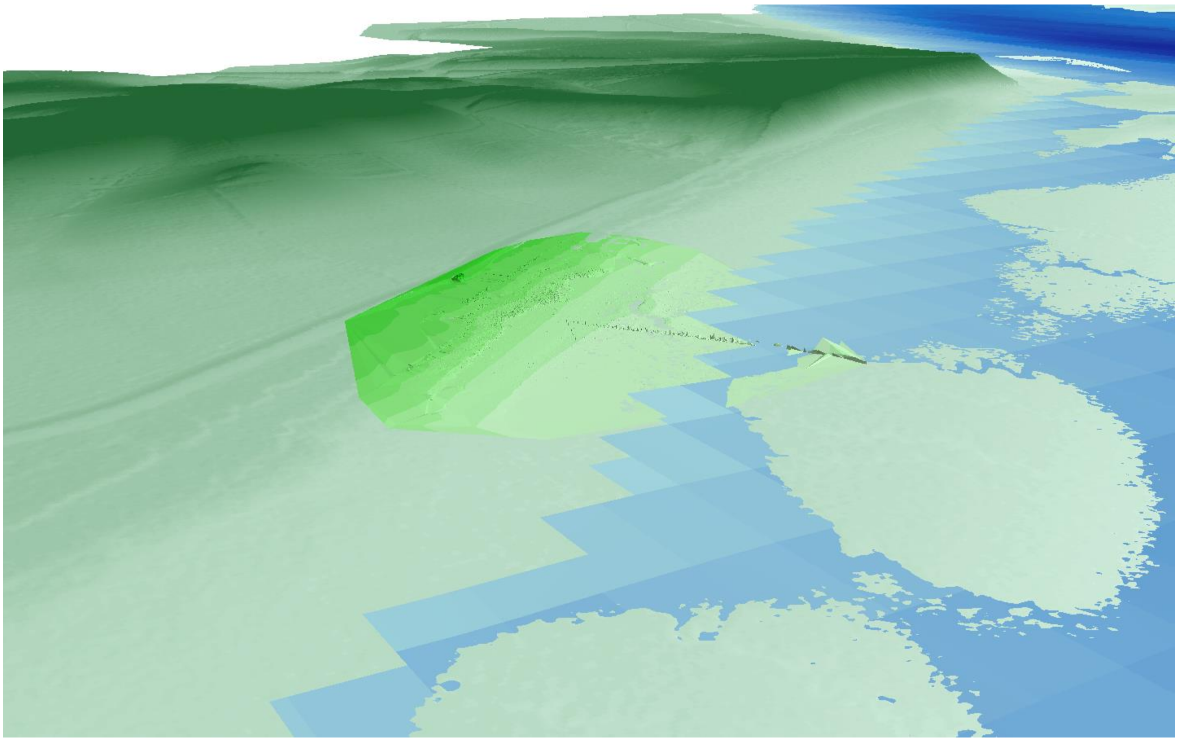

Figure 51 - The combined TLS, ALS and Bathymetry survey of the structure at Aust viewed from the northeast in ArcScene

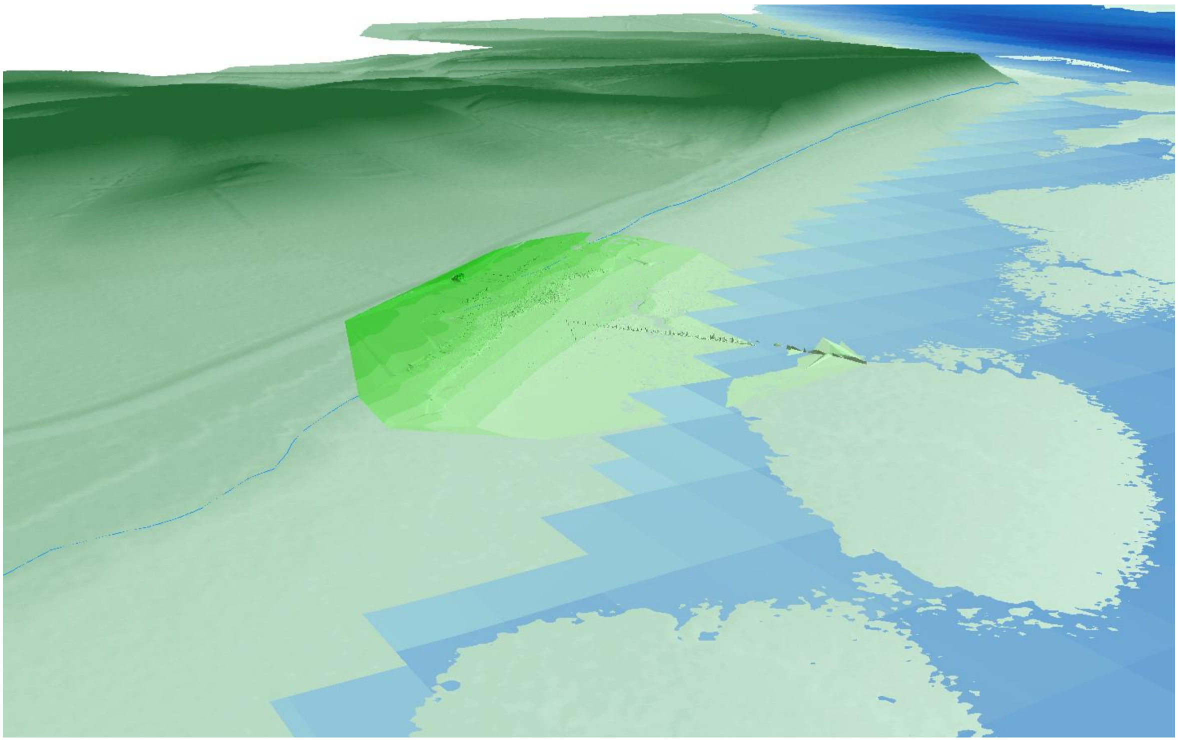

Figure 52 – The combined TLS, ALS and Bathymetry survey of the structure at Aust with the Ordnance Survey high water line (in blue) viewed from the northeast in ArcScene

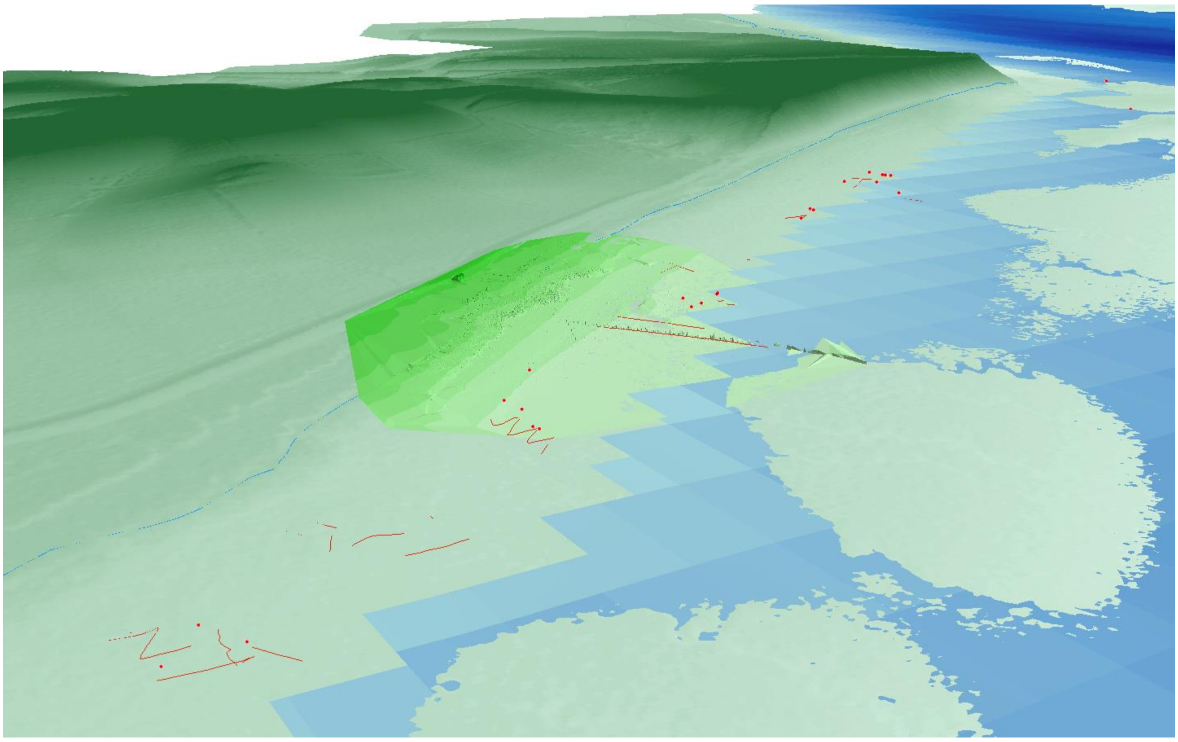

Figure 53 – The combined TLS, ALS and Bathymetry survey of the structure at Aust with the Ordnance Survey high water line (in blue) and RCZAS lines and point data (in red) viewed from the northeast in ArcScene

Additional data sources were also imported into the GIS database for examination. These included .shp files from the Ordnance Survey showing underlying geology, statutory boundaries such as parish and county borders, and a range of hydrographic information including scheduled wrecks. Whilst these datasets contained no information relevant to the area within the case study, the ability to import and view such data is nonetheless significant as a number of coastal and intertidal sites can be better understood in the context of such information.

4.4 Integrating Terrestrial Laser Scanning with Existing Datasets

No one survey technique can provide all the scales of resolution needed for a complete archaeological record, or a complete understanding of landscape. The ability to integrate a variety of forms of metric information into a single database system maximises the usefulness of each individual survey whilst also allowing for a multi-scale approach to recording landscapes. Within coastal and intertidal landscapes, the ability to integrate varying forms of information is essential as terrestrial and marine landscapes demand different survey technologies which have significant differences in their resolutions and accuracies. Alongside the measured survey of landscape, integration with non-metric data forms such as imagery and cultural information can greatly enhance the value of topographic data. The ability to overlay additional information on top of measured data means that sites and structures can be linked to details on their construction, date and function, but also means that they can be viewed in the context of surrounding archaeological sites, many of which are not visible above ground or above the water level.

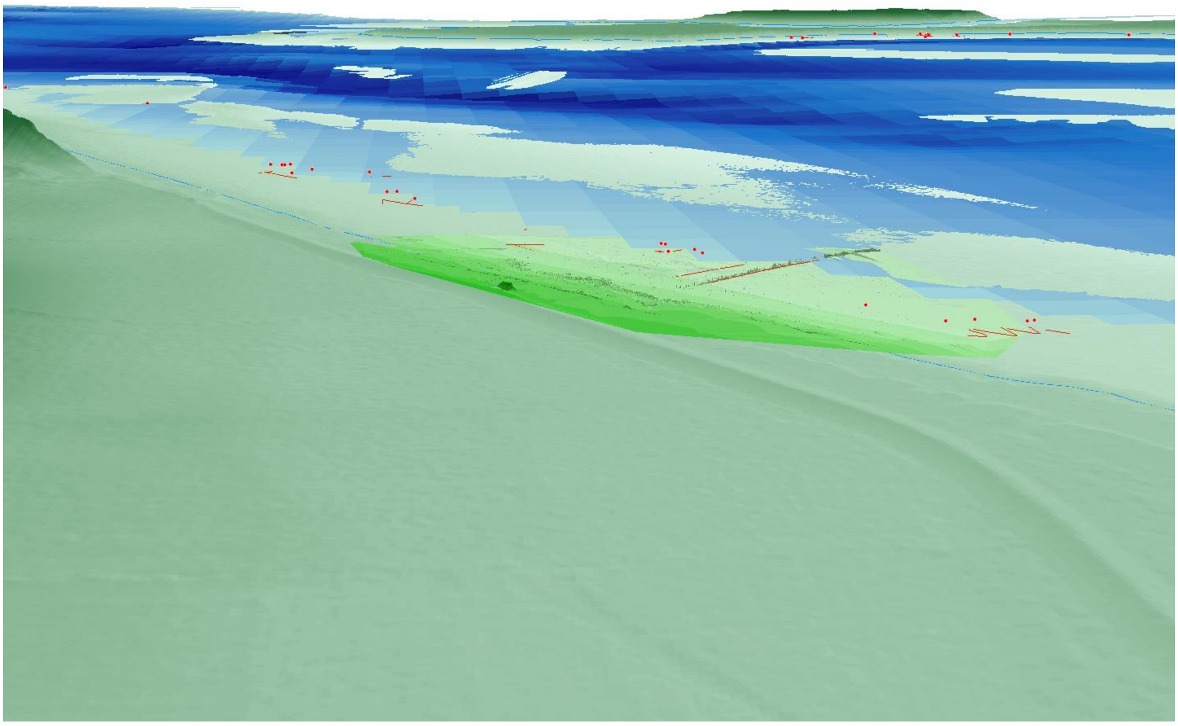

Figure 54 – The combined datasets of the structure at Aust looking west across the Severn in ArcScene

Figure 54 shows how this can be used to indicate the presence of sites across landscapes which would not be directly visible within the landscape but which nonetheless have an important relationship with the site at Aust. Likewise information such as the high water mark and parish or administrative boundaries can be useful in the interpretation of intertidal sites, as they place them within a cultural as well as topographic landscape. This is particularly pertinent in understanding specific fishing technologies such as those used in the putcher rank at Aust, as it is essential that such structures be understood within their topographical, ecological and cultural landscape. The variety and proliferation of migratory species in the Severn Estuary and its particular and unusual tidal range has led to a number of specialist fishing techniques being developed which are unique to this landscape, and examination of the site must therefore be grounded within a wider understanding of the landscape. Further geographical information on factors such as piscine habitats could be placed within the GIS database to help understand fishing structures whose function is less clear.

Difficulties can occur in the integration of disparate data sources due to variations in their accuracy, resolution and purpose, and so it is imperative that there is an understanding of what each data source represents. It could be argued that such integration limits the usage of the metric data for scientific analysis as the overall database can only be as useful as the least accurate dataset. In this case study, the varying accuracy of the *Z* values of the different datasets has been problematic. As will be seen in the next chapter, the ability to accurately place intertidal sites within their vertical frame is essential to an understanding of their function. However, as a visualisation, interpretation and management tool, the use of GIS software has significant advantages over other approaches. When integrating data from different sources it is imperative that we move away from the idea that every piece of data can or should be maintained. This approach is typical of archaeological recording, where very often the emphasis is on recording the maximum amount of information possible rather than tailoring the amount of information gathered to the needs of the individual survey. In the case of the structure at Aust a non-decimated terrestrial laser scanning dataset was able to be used within ArcGIS; however, this is unlikely to be the case with a more complex dataset or with multiple datasets. The level of accuracy needed in survey is proportionate to the resolution at which the dataset is used. If the placement of sites at a landscape level is being examined, then the manner in which terrestrial laser scanning data is used has to be constrained by the scale of the overall landscape study. GIS software is now used as standard in heritage management, so it is essential that if terrestrial laser scanning is being used to record archaeological sites, then the information gathered must to some degree be capable of use within such software.

The method used in this case study is by no means perfect, in part due to inherent problems in using pre-processed datasets and in part due to the use of a 'best-fit' software package. Another option may have been to use game engine software which would have been capable of rendering all of the different datasets at their full resolution in three-dimensions. However, whilst this would have resulted in a perfect representative visualisation, there would have been no means to attach additional information to the surfaces. ArcGIS is designed to allow the visualisation of information within a landscape setting, and is the industry standard for such, therefore, whilst the terrestrial laser scanning data could have been transformed into a more detailed three-dimensional surface, its position and relationship to the other datasets, as well as key values such as heights have been preserved. In addition, the workflow is fast and did not require any specialist modelling software, and once established provides a method for rapidly integrating terrestrial laser scanning data with readily accessible topographical datasets, thereby vastly increasing the potential of intertidal and coastal survey using terrestrial laser scanning. One clear advantage that can be added by this approach is its applicability to the Rapid Coastal Zone Assessment Survey (RCZAS). There are still areas of the country without a completed RCZAS, and even where they have been completed; it could be argued that RCZAS is an ongoing process, as new sites are revealed by research, erosion and the application of new technologies. The ability to combine and display all the existing data prior to further survey being carried out allows for more targeted survey and research to occur (See Chapter 9 below).

Chapter 5: Correlating Structures within an Intertidal Landscape: Sites in the Léguer Estuary, Brittany

> *Guided by God, below the city which is above Léguer, unhurt in her coracle, she landed safe and well. There lay an enclosure of squared stones built in the sea below the city, and when the sea retreated, she was left on the dry sea shore. The next morning, the keeper of the enclosure came to collect his customary catch (as every day fish of the normal type were regularly found), expecting only food. Finding something he had never found, a coracle, he at first recoiled, but guided by hope she came forth from hiding, was received, and bringing her secretly under his cloak he hid her in part of the house.*
>
> Extract from the Life of St Efflam (de la Borderie 1892; translation mine)

This chapter will look at the use of terrestrial laser scanning (TLS) in determining the function and relative chronologies of archaeology sites within an intertidal and coastal landscape by placing them within the context of the tidal frame. The inherent relationship between intertidal sites and their relative sea level and most importantly their relation to the tidal frame is one that is not fully understood. Most studies assume that structures which occupy different areas of the

Figure 55 – Map of the known intertidal structures within the Léguer estuary 1. Dourven-A 2. Dourven-B 3. Corps de Garde 4. Baie de la Vierge 5. Petit-Taureau (D) 6. Poull Mad Dogan 7. Petit-Taureau (A)

tidal frame must also differ in terms of function or of date, but no clear examination of this relationship has taken place. An examination of the comparative positions of intertidal structures across a wider landscape may provide evidence of their relative chronology and function.

The sites featured in this case study are all located within the estuary of the Léguer River around 5 km west of Lannion within the Côtes-d'Armor department of Brittany. The Léguer is approximately 61.3 km long, the last 9km of which are estuarine. The river empties to the west into the Bay of Lannion, and is thus sheltered from the stronger currents of the Channel to the north. Downstream of the le Yaudet promontory the estuary widens significantly and it is here that the bulk of the intertidal structures are located. The left (south) bank of the river is dominated by the promontory of le Yaudet, at the foot of which is the Baie de la Vierge where the ruisseau du Yaudet enters the estuary. Enclosing the Baie de la Vierge is a large curved wall which is known locally as 'le mur du pêcherie' – 'the wall of the fishery' (4). To the west of the Baie de la Vierge a large rectangular line of stones is located at the higher end of the tidal range. The function of this structure is unclear and it is not included in this study. Further to the west the short curved line of stones at Poull Mad Dogan has been tentatively identified as a fishing weir (6), with two further V-shaped weirs to the west at Dourven (1 & 2). Along the right (north)

Figure 56 - The 'Pêche miraculeuse' at le Yaudet 30th March 1938 (© Service Régional de l'Inventaire de Bretagne)

bank of the river the large V-shaped structure at le Petit-Taureau contains four distinct phases of weir built in stone (7), with an earlier timber phase identified through excavation in 2012 and 2013 (5). Further downstream (west) another smaller V-shaped structure, Corps de Garde, is evident (3).

Figure 57 – One of the many buildings on the headland of le Yaudet constructed from the local *granit de Plouaret.* The roughly squared nature of the masonry is similar to the construction used in the intertidal structures throughout the estuary.

The Léguer estuary is a site du réseau Natura 2000, a designation applied to maintain the biological diversity of an area, with the emphasis for the Léguer being on the reestablishment of fish stocks. Today the estuary has migratory species of sea trout (*Salmo trutta*), atlantic salmon (*Salmo salar*), and European eel (*Anguilla anguilla*), and was likely home to the same species at the time the various structures within the estuary were in use. Historical evidence also exists for the catching of a large shoal of herring (*Sardina pilchardus*) behind 'le mur du pêcherie' in the Baie de la Vierge (Figure 56). However, this appears to have been notable for the unusual nature of the event, rather than representing the intended purpose of the structure. The dating and relative chronologies of the structures within the estuary has been problematic, the extant remains are drystone built and constructed of the local bedrock, 'le granit de Plouaret', a rose granite whose exposures naturally weather into large square blocks. This natural squaring accounts for its prolific use in both the intertidal structures and the local vernacular architecture at le Yaudet and other nearby villages (Figure 57). However, the rough-hewn nature of the architecture makes the various structures very difficult to date stylistically, and the inorganic nature of the material used in their construction offers little opportunity for scientific methods of dating.

Terrestrial laser scanning (TLS) offers the ability to accurately record comparative heights of the structures across the estuary at a landscape level, whilst also allowing the rapid detailed recording of intertidal excavations under challenging conditions. Insertion of this data within the modern tidal frame allows for the analysis of varying interpretations of chronology and functions of the structures on site.

5.1 The Léguer Estuary: A Landscape of Production

Previous archaeological and historical research on the Léguer estuary has mainly focussed on the settlement of le Yaudet. The le Yaudet headland has significant earthwork fortifications dating to the Iron Age and Roman periods, and continued in importance through the early and high medieval periods as a religious centre for pilgrimage with significant links to the lives of St. Enora and St. Efflam, two prominent 6th century missionaries. Consequently it has always been assumed that the settlement at le Yaudet had a strong monastic element from the early medieval period onwards. The association with St. Enora and St. Efflam is known through later documents of 12th to 17th century date, which mention an enclosure of squared stones in the river below the headland of le Yaudet (see quote at the beginning of this chapter), implying the presence of one or more of the intertidal structures by the 6th century.

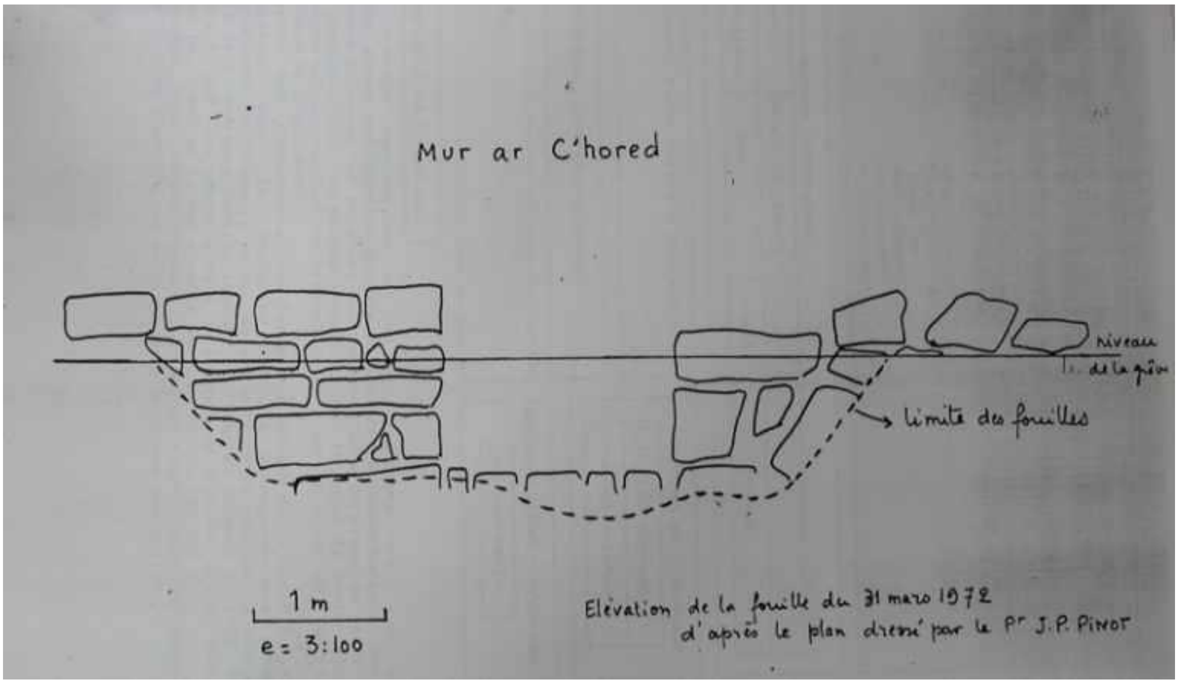

Figure 58 – Drawn section of the 1972 excavation of one of the sluice openings on 'le mur du pêcherie' at le Yaudet (Pinot 1991)

The first archaeological investigations of note were carried out in the 1970s, but were not widely published, and are mainly known through reproduction in later texts. Significantly they feature an excavation across a sluice in the mur du pêcherie at le Yaudet, revealing the fuller extent of the structure (See Figure 58).

The settlement of le Yaudet on the south side of the river was further surveyed and excavated in a series of works from 1991-2002. The settlement was revealed to have Bronze Age origins prior to the construction of the substantial Iron Age to Roman fortifications, with a significant medieval settlement later occupying the headland (Cunliffe and Galliou 2004). The excavations focused primarily on the headland, with little work carried out on the surrounding landscape, although the 'mur du pêcherie' was surveyed using a total station to create a digital 'stone-by-stone' plan (Figure 65).

Figure 59 – Timber structure revealed during excavations at le Petit Taureau in 2012, below the later stone built structure at the lower end of the tidal frame (Langouët *et al.* 2012a). The baseplates appear to have been used to form a triangular reinforcement to support the line of the post and wattle built fishing structure.

In 2006 the *Association Manche Atlantique pour le Recherche Archaéologique dans les Îles* (AMARAI) commenced the 'Maritime Fish-traps of Brittany' project, designed to quantify and characterise the large number of fishing structures around the Breton coastline (Langouët and Daire 2009). The resulting fieldwork compiled a database of over 550 structures. One of the key sites identified for further investigation was the large V-shaped structure in the Léguer estuary at le Petit-Taureau, which had at least four distinct phases and so presented an opportunity to look at the development of such structures over time. A programme of excavation in 2012 led to the discovery of a much earlier timber built V-shaped fishing structure directly underlying one phase of the stone alignments. The excavations revealed a line of wattle and post construction, supported by a finely crafted mortice and tenon sill-plate with triangular stanchions similar to the 'hurls' known from Irish weirs, which would have been filled with stones to stabilise the walls of the structure and prevent their destruction in strong tides or storms (Went 1984). The timber structure represents a substantial investment of skill, with finely constructed mortice and tenon construction, and has been dated through dendrochronology to 615 AD (Bernard and Langouët 2014).

In June 2013 further excavations took place in an effort to locate the sluice at the apex of the timber built fishing structure.

5.2 Placing of Sites within an Intertidal Landscape

The 2013 excavation afforded the opportunity to record the exposed timber structure with terrestrial laser scanning, and to place the excavated remains within the context of the related overlying structures, as well as the range of different structures across the estuary. This also provided the opportunity to look at these relationships within the context of the tidal frame, and to assess the potential for this approach to aid in the interpretation of the structures both in terms of their function and their relative chronologies. As noted above (Section 2.2.4) differing forms of intertidal structure require fixed areas of the tidal frame to operate. It has

No.	Site	Nb (m)	δ(PHBMme) (m)	Attributed age
1	Trédrez, Dourven-A	0.40 ± 0.20	3.70 ±0.10	Bronze Age
2	Trédrez, Dourven-B	0.70 ± 0.20	3.40 ± 0.10	Bronze Age
3	Servel, Corps de Garde	1.70 ± 0.10	2.40 ± 0.10	Iron Age
4	Ploulec'h, Baie de la Vierge	2.38 ± 0.10	1.70 ± 0.20	Gallo-Roman to High Medieval
5	Servel, Petit-Taureau (D)	2.45 ± 0.05	1.60 ± 0.10	650 AD
6	Ploulec'h, Poull Mad Dogan	2.80 ± 0.30	1.30 ± 0.30	High Medieval
7	Servel, Petit-Taureau (A)	2.90 ± 0.10	1.20 ± 0.10	Late 15th century

Table 7 - Relative ages of structures at Léguer estimated from their position within the tidal frame (Langouët *et al.* 2012b)

therefore been assumed that intertidal structures have the potential to be used as benchmarks for sea level, by providing a datable height of fixed points within the tidal range (e.g. Bannerman 2011). Previous work within the Léguer estuary by Langouët *et al.* (2012b) has taken this approach and assumed that the dates of the intertidal structures within the estuary can be calculated by comparing their varying heights (See Table 7). In this approach the base of each intertidal structure (Nb) is assumed to be at the level of the 'plus haute basse mer de morts-eaux' (PHBMme) or lowest neap tide. The difference between this level and the modern datum is then calculated (δ(PHBMme)), and used to provide a relative date.

Whilst this is a useful hypothesis, it assumes firstly that all of the structures within the Léguer estuary are related to fishing, and therefore require the 'PHBMme' to operate and secondly that the relationship between intertidal fishing structures and the tidal frame is a rigidly fixed, meaning that structures can rely on only one tidal state to operate. Whilst some intertidal structures do rely on a rigid relationship to the tidal frame, such as salterns or tide mills which require only the upper end of the spring tide to operate, intertidal fishing structures are not necessarily limited to a specific area within the tidal range. Evidence from both the Severn Estuary and the South Pacific attest to the building of fishing structures at different heights in the tidal range to exploit a fuller range of tides, from high water spring tides to low water spring tides (Dennison 1985; Memmott *et al.* 2008). Therefore, it must be borne in mind that structures occupying different areas of the tidal frame may be of similar function, but designed to exploit differing tidal states. Nevertheless, a more careful examination of the positioning of structures within the contemporary tidal frame may allow for several conclusions to be drawn. Whilst it can in no way be assumed that the modern relative sea level and tidal frame are a constant, the placement of sites within the modern tidal frame can in some cases be used to infer both their previous function and the relative movement of the tidal frame. At a very basic level this can be a simple binary outcome, if an intertidal site lies outside the modern tidal frame the tidal frame has moved, likewise if a non-intertidal site, such as Seahenge, has been moved to within the modern tidal frame the tidal frame has moved (although whether this movement is horizontal or vertical is more difficult to ascertain). At a broad level, a site's position within the tidal frame can be used to define what it cannot be. For example the tidal range within the Léguer estuary is 7.85m for a spring tide; it is extremely unlikely therefore that the surviving structures near the MHWS line were ever located near to low water and vice versa that those at the MLWS line were ever located at the high water end of the frame. What is notable about the previous studies of coastal and intertidal archaeology within the Léguer estuary is that the structures are assumed to be independent of each other. The study of le Yaudet neglected the wider hinterland of the settlement, whilst the surveys of fishing structures assumed that each were of independent date. The following approach uses the collection of structures, some dated, and some undated, to test the hypothesis that correlation with each other, and the modern tidal frame can unpick the relationship between site function and the tidal frame.

5.3 Terrestrial Laser Scanning of Intertidal Excavations

Figure 60 – The remains of the 7th century AD fishing structure at le Petit Taureau exposed during fieldwork in 2014 at a low spring tide.

The terrestrial laser scanning survey of the timber-built fishing structure was carried out while the excavation was ongoing, from the 25th-28th June 2013. The excavated sections of the 7th century V-shaped structure were recorded, along with the extant 16th-18th century stone-built structures. In addition a stone-paved trackway leading down to the beach, contemporaneous with the later structures, was also surveyed, as was the smaller V-shaped fishing structure at Corps de Garde to the west of the site. In November 2014 a return visit was made to record the structure in the Baie de la Vierge, to the west of the promontory of Le Yaudet.

Equipment Used	Positional Accuracy
Leica ScanStation C10 TLS	±6mm
Leica 1200 GNSS	±20mm
Registration Error	±5mm
Cumulative Uncertainty	**±31mm**

Table 8 - Cumulative uncertainty in the survey at Léguer

The TLS survey was carried out using a Leica ScanStation C10 and the individual scans were registered together using HDS targets. Structures were recorded to a resolution *c.*4mm. GNSS was used to survey in the target locations, creating a final registered accuracy of *c.*15mm. The registered scans from each survey were incorporated into a single database allowing comparison of the structures.

Figure 61 - The stone built intertidal structure at the foot of le Yaudet viewed from the west at mid tide.

Excavation within the intertidal zone is extremely challenging due to both a limited timeframe for work and the considerable risks posed by the environment. The 2013 fieldwork was carried out on structures which lay low down in the tidal frame, around the MLWN mark. In order to maximise the available time on site, the fieldwork was carried out during a low spring tide when the exposure of the site was greatest. The height of MLWS at Locquemeau is 1.4m above Chart Datum, meaning that on all but one of the days of fieldwork the tide fell to well below the MLWS mark (See Table 9 below). Despite this, the fieldwork on site was limited to a 3-4 hour window; including re-excavation of the previous day's work (which had been partially covered by sediment), bailing out of the trench, further excavation of the structure and recording of the exposed remains. This heavy workload meant that the terrestrial laser scanning of the structure was limited to a period of around 30mins at the end of each day's work prior to the tide recovering the site. The incoming tide was extremely rapid, a phenomenon typical of estuarine environments (Pugh 2004), and the underlying strata very soft, so as a consequence the scanner was subject to subsidence due not only to the incoming tide but the rising freshwater table in advance of the tide coming in. The subsidence frequently caused the scanner to go off level, leading to the loss of accuracy and a requirement for the work to be repeated. The 2014 fieldwork took place at the higher end of the tidal range and as such was not limited by tides. However, as the site sits on the course of the ruisseau du Yaudet similar problems with groundwater and stability occurred.

Date	Low Tide - Time	Height (m above CD)
25th June 2013	14:47	+00.96
26th June 2013	15:35	+01.07
27th June 2013	16:22	+01.36
28th June 2013	17:59	+01.81
6th November 2014	12:47	+01.26
7th November 2014	13:30	+01.13
8th November 2014	14:12	+01.18

Table 9 – Heights and times of low tide during fieldwork in the Léguer estuary in 2013 and 2014

The standard workflow proposed in Section 3.6 for relating elevation to the tidal frame proved problematic in relation to this site, due to issues in transforming the GNSS data from WGS84 to a local mapping frame. At the time of collection the local mapping system was not available for the GNSS and the data was collected within the WGS84 co-ordinate system. Converting this directly to the local French mapping systems was problematic as several mapping frames exist. In the end the *x* and *y* coordinates were derived by converting the WGS84 coordinates to UTM zone 30U for use in Cyclone software, whilst the calculation of the elevation was in the end made relatively simple by the presence on site of a benchmark related to the Chart Datum (zéro hydrographique) at Locquemeau. As one of the TLS targets had been positioned directly over this benchmark, it was relatively simple to translate the *z* values of the dataset to this datum.

Figure 62 - Location of Standard and Secondary Ports relevant to the Léguer estuary.

Placement of intertidal sites within the tidal frame requires access to tidal data, in this case the SHOM (Service Hydrographique et Océanographique de la Marine) 2014 predicted tides for Locquemeau. Locquemeau is a Secondary Port, the Standard Port for which is Roscoff. Three Secondary Ports exist around the bay of Lannion, Trébeurden to the north, Locquirec to the south west and Locquemeau at the mouth of the river Léguer. All are very similar in terms of tidal range (See Table 10) meaning that interpolating the tidal heights for any point on the coast between them is relatively straightforward. The sites at Léguer are located within an estuary rather than on the open coast, and could therefore potentially be affected by the additional water supply from the Léguer and *ruisseau du Yaudet*. However, any effect on water level within the estuary is likely to be seen at the low water levels with no discernible effect on the high water levels (Pugh 2004) and so can be discounted as a significant influence on the overall height on the water within the estuary.

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Roscoff	+00.18	+01.30	+03.40	+05.30	+07.10	+08.90	+09.80
Trébeurden	+00.23	+01.40	+03.55	+05.48	+07.40	+09.25	+10.15
Locquirec	+00.45	+01.55	+03.55	+05.49	+07.35	+09.25	+10.13
Locquemeau	+00.17	+01.30	+03.45	+05.38	+07.30	+09.15	+10.06

Table 10 - Tidal heights at Standard and Secondary ports relevant to the Léguer estuary.

Several issues must be noted when using tide table data. Firstly, the figures are based on predictive rather than actual heights and as such represent the astronomical effect on tides without taking into account the supplementary meteorological effects. Ideally, actual heights would be available using real-time measurements of the tidal level, however, these are only gathered at Standard Ports, the nearest being Roscoff, and there is no easy translation of this data to Secondary Ports. Discounting meteorological factors is not, however, problematic as the predicted data is based on an averaging of measured data from the Standard Port, gathered over the previous 3-5 years, and would normalise these factors. In the case of Locquemeau an additional tidal datum also exists in the form of research carried out on the effects of Storm Johanna on 10th March 2008, which led to a storm surge of 2.144m higher than the predicted spring tide (Cariolet 2010).

5.4 Results and Interpretation

5.4.1 Comparative heights and morphology

The data gathered by the TLS survey was georeferenced using the GNSS data, imported into AutoCAD software, and used to generate two-dimensional sections of each structure. These sections were then plotted against each other with reference to the local mapping frame (IGN69) and zéro hydrographique (ZH), the French equivalent of chart datum (Figure 63).

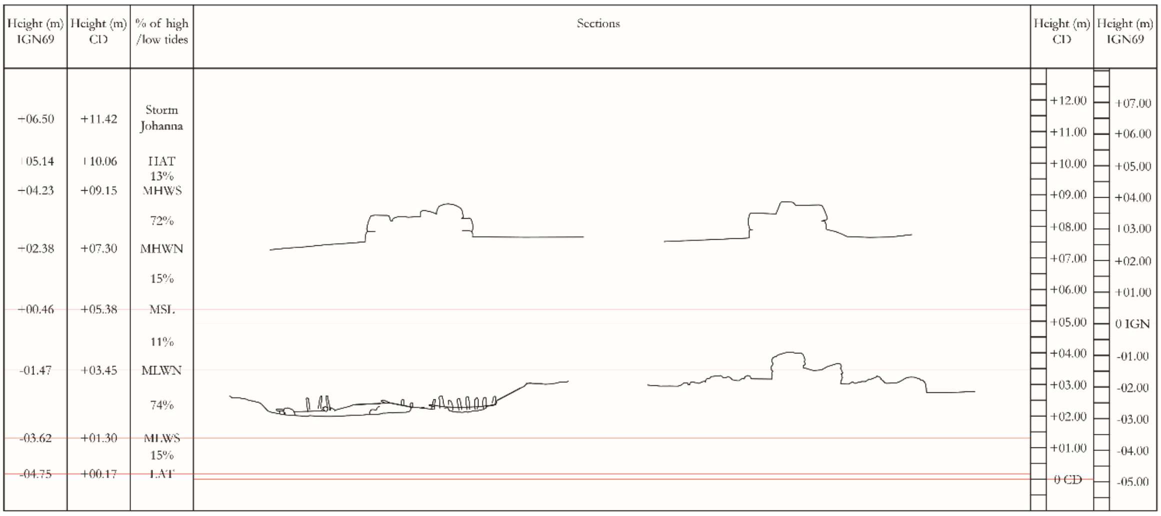

Figure 63 - Comparative heights of structure within the Léguer estuary.

The cross-sections enable a direct visual comparison of the vertical placement of structures across the estuary within the tidal frame, and immediately allow some basic conclusions to be drawn. The most obvious is the relative heights of the structures at le Yaudet and le Petit Taureau, suggesting that the structures were exploiting different ends of the tidal frame and therefore fulfilling very different functions. The relative heights of two phases of structure at le Petit Taureau suggest that the later structure sat higher in the tidal frame, potentially suggesting a shift in the RSL at this point. However, the cross-section of the C7th weir indicates that the timber sill beam has curved over a large underlying rock, implying that the structure has been pushed downward into the sediment by the weight of the overlying stone-built phase. This would imply that the 7th century AD structure originally sat at a higher position within the tidal frame, perhaps by as much as 0.5m. The earlier phases of the structure at le Petit Taureau were first exposed due to an industrial level of sand extraction in the late 20th century (Figure 64), causing channel migration and displacement of sediments through the estuary. This relationship between the structures and the sediment is important, as it suggests that the various phases of rebuilding of the structure, and the increased height at which subsequent phases were built, could therefore be attributed to the gradual increase of the level of the foreshore due to sedimentation caused by the structures themselves.

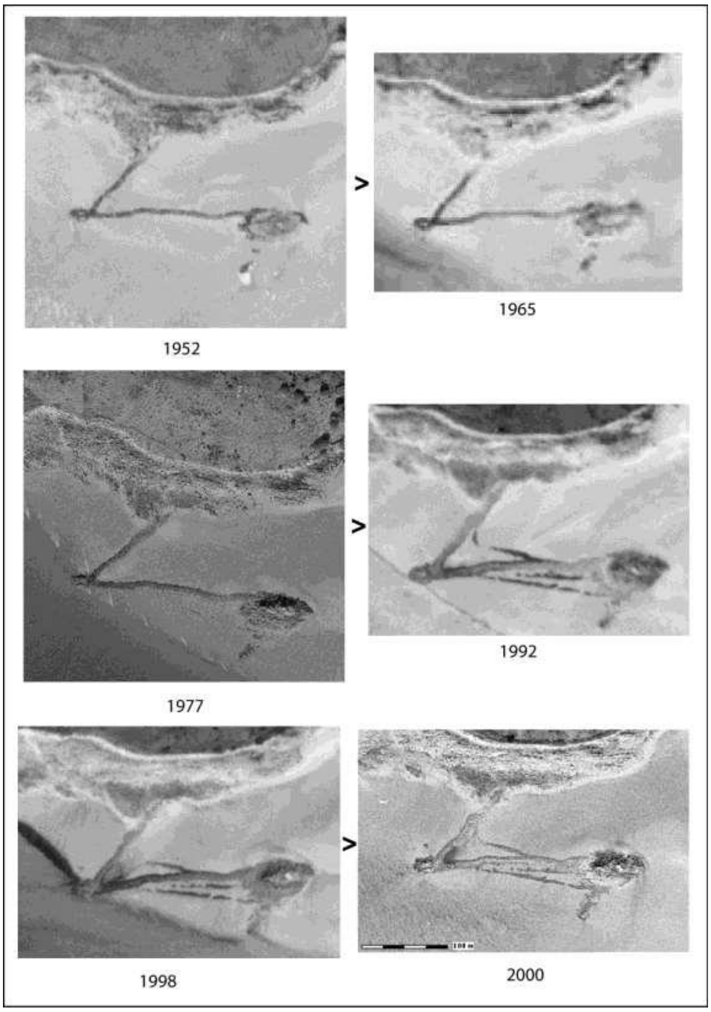

Figure 64 - Aerial photos from 1952 to 2000 showing the progressive exposure of the structure at le Petit Taureau (Langouët *et al.* 2012b). Note the exposure of earlier phases of the structure in the later photographs.

The placement of the structures within the tidal frame may also be used to explain their differences in both size and morphology (See Section 2.10 above), and provide an alternative explanation to the chronological explanation put forward by Langouët *et al.* (2012b). The large fixed fishing structures at le Petit Taureau are situated between the MLWN and the MLWS levels, where 74% of low tides fall. It would follow that the principal investment in the construction of fixed fishing structures would be within this area, as it would maximise the return of investment by providing the largest amount of fish. The smaller weirs at Dourven and Corps de Garde fall below the level of the MLWS but crucially not below the level of the LAT. There is therefore no reason to assume that they were not contemporary with the large structure at le Petit Taureau, as they would still have been exposed, and therefore been functionally, during extremely low tides. 15% of low tides fall within this range and it may be postulated that the relatively small size of the weirs and their position within the tidal frame are not due to their relative antiquity, as proposed by Langouët *et al.* (2012b), but to the lesser exposure of this area of the foreshore and the lesser reliance on the structures for provision of fish.

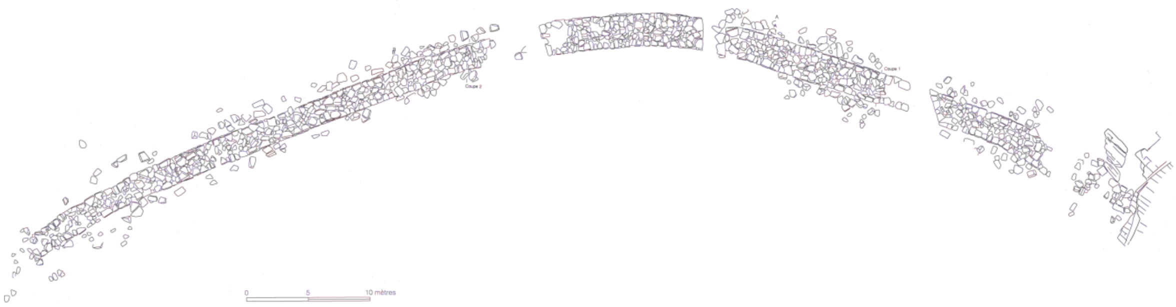

Figure 65 - Plan of the stone built structure at Le Yaudet produced by total station survey (Cunliffe and Galliou 2004)

A comparison of the sections also reveals slight differences in the morphology of the structures at le Petit Taureau compared to those at le Yaudet. The walls of the structure at le Yaudet are slightly inclined at an angle of around 6° from the vertical, differing in profile from the structure of le Petit-Taureau which has pronounced perpendicular construction in the areas of extant blockwork. Similarly in plan the structure differs, resembling a gentle arc rather than the V-shape which defines the other fishing structures within the estuary. The structure is also perforated by several openings which appear to have functioned as sluices, and which have no comparable features with the structures at le Petit Taureau. The structure at le Yaudet had previously been comprehensively surveyed as part of the investigations into the site at Le Yaudet (Cunliffe and Galliou 2004), and a stone by stone plan produced (Figure 65). However, whilst the plan of the structure is highly accurate it was produced only in two dimensions with no datum height, and consequently no relation to the wider landscape context, particularly in relation to the tidal frame. Likewise the earlier section drawing by Pinot has no elevation datum.

In particular the Pinot excavation is important as it uncovered the base of the presumed sluice, and so would have provided valuable information about the positioning of a diagnostic feature of the structure in relation to the tidal frame. Alignment of the earlier Pinot drawing with an elevation generated from the laser scanning data allows the accurate placement of this significant feature within the tidal frame (Figure 66).

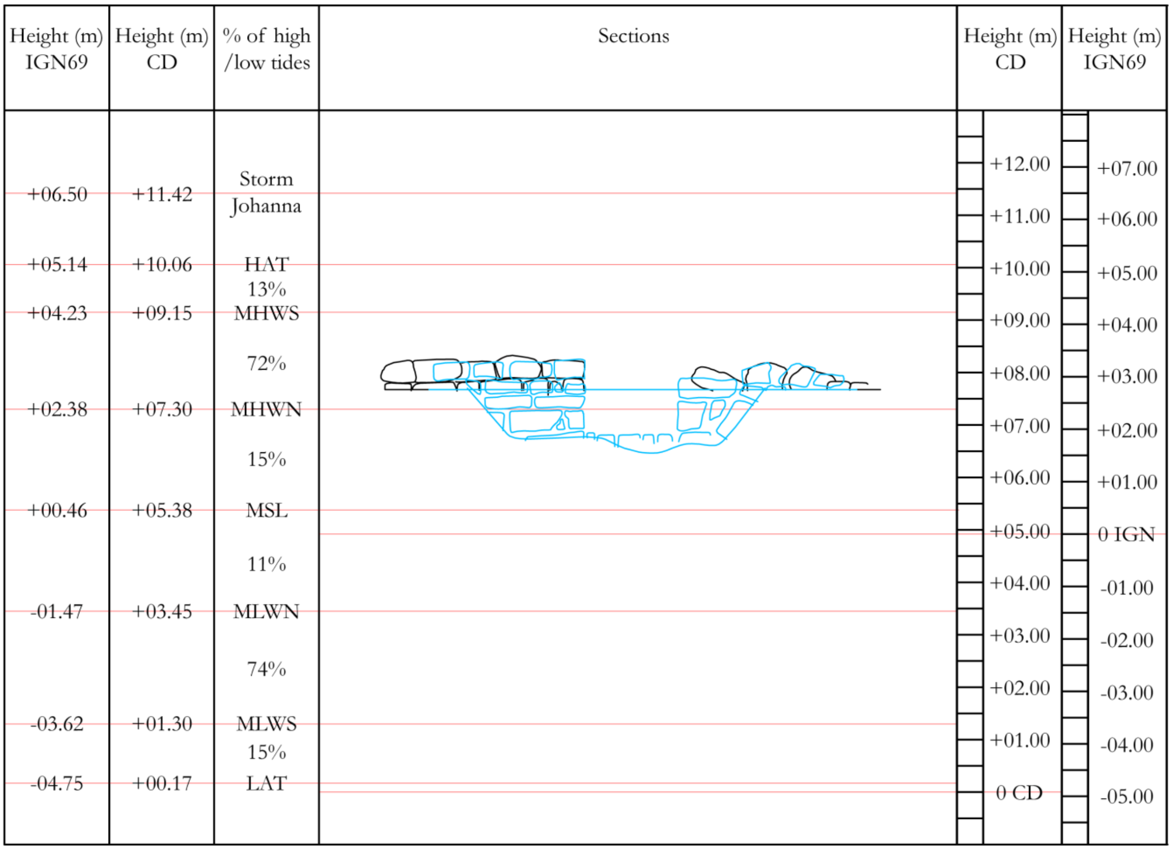

Figure 66 – The elevation of the Pinot excavation (in blue) rectified to the elevation generated from the 2014 terrestrial laser scanning survey and compared.

The results compare neatly with the tide mill uncovered at Nendrum, Northern Ireland, where the base of the millrace pond sat approximately 0.5m below MHWN. All of these factors combined support the hypothesis that the structure at le Yaudet is of a differing function from those on the other side of the river, and is most likely the reservoir for a tide mill. The next section will explore this possibility further using volumetric analysis.

5.4.2 Volumetric Analysis at Le Yaudet

As noted above, a comparison of the heights and morphology of the various structures across the estuary raises the possibility that the structure in the Baie de la Vierge to the west of Le Yaudet could represent the reservoir for a tide mill. There is sufficient doubt over the function of the structure at le Yaudet to justify investigation, and indeed it has previously been suggested as a tide mill (Cunliffe and Galliou 2004), although no additional work was carried out to support this assertion. Of the 150 known tide mill sites in France, 90 are located in Brittany (Charlier *et al.* 2004) and the Léguer river itself has a multitude of watermills of varying types and ages along its length, some of which are still functioning. The estuary of the Léguer is an ideal location for tide mills, as they require an indented coastline with otherwise unused inlets that could easily be blocked off (Charlier *et al.* 2004). The placement of the structure at the top end of the tidal frame is consistent with the siting of tide mills, which required a tidal coefficient of 65 to 70 to operate (Wailes and Gardner 1938). In practice this meant that they were sited at a point in the tidal frame three hours above the turning tide (Charlier and Menanteau 1997). The presence of 7th century AD constructions on the north side of the estuary, and the association of the structure with the Life of St Efflam, raises the possibility that the 'mur de pêcherie' is of an early medieval date. In this case it would be directly comparable to the 7th century AD sites of Ebbsfleet (AD 691-2) in Kent, England (Hardy *et al.* 2011), Nendrum (AD 619-621) in County Down, Northern Ireland (McErlean and Crothers 2007), and Little Island (AD 630) in County Cork, Ireland (Rynne 2000). All of these examples are on narrow tidal creeks and on sheltered parts of the coast, with those that also use a freshwater source placed where a small stream enters an estuary (Wailes and Gardner 1938). Again this is directly comparable to the structure at le Yaudet.

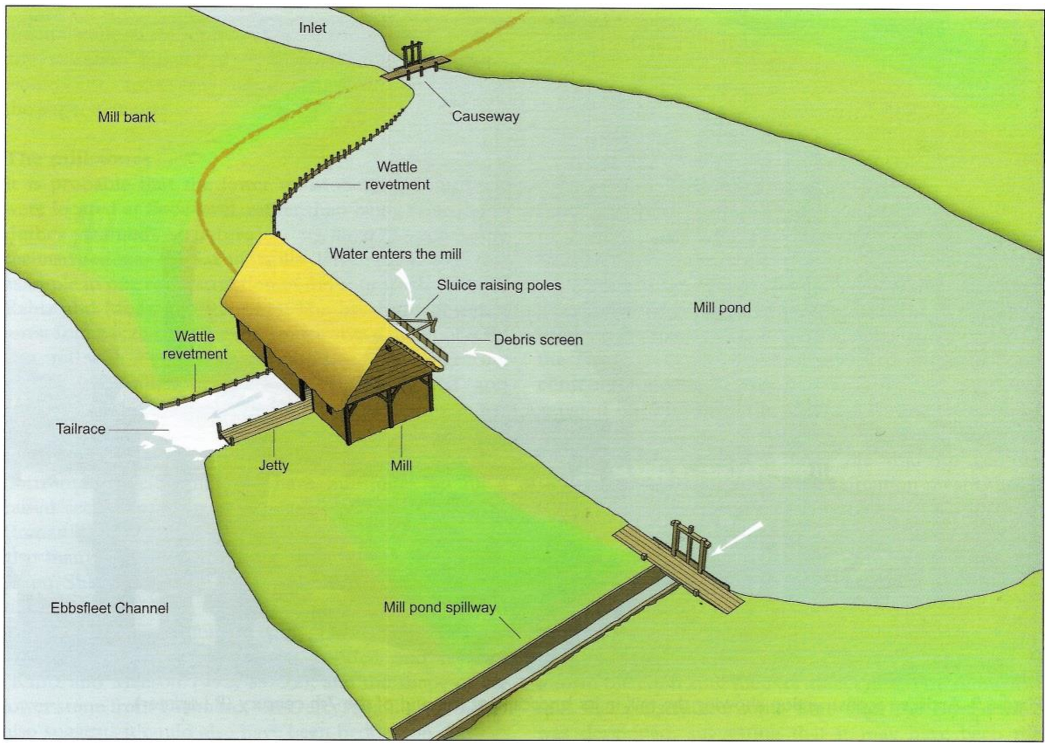

Figure 67 – An artist's reconstruction of the 7th century AD tide mill at Ebbsfleet (Hardy *et al.* 2011).

The lack of evidence for a wheelhouse is not as problematic as might seem, as most mills of an early date, such as Nendrum, Ebbsfleet or Killoteran were constructed almost entirely of wood

(Hardy *et al.* 2011). Horizontal mill wheels, common in tide mills of most periods, would have meant that structure sat above the wall and sluice (See Figure 67 above). As noted above (Section 2.10) there is an intrinsic difficulty in ascribing function to structures within the intertidal zone due to similarities in morphology, or the potential for structures to fulfil multiple resource utilisations. The suggestion that the structure had the primary function of a millpond does not preclude its usage for catching fish, the tide mill at Nendrum was originally thought to have been a fishing structure prior to its extensive excavation (McErlean and Crothers 2007). Without extensive excavations of the site at le Yaudet (which in themselves may be inconclusive) it is difficult to conclude that it is definitely a tide mill. However, the potential for the Baie de la Vierge to act as a reservoir for a tide mill can be assessed using the data gathered from the terrestrial laser scanning survey. Work by Browne (2007) on the efficiency of the mill at Nendrum provides a model by which this volumetric data can be used in conjunction with tidal data to assess the potential outputs of a tide mill. In order to calculate the potential volume of the Baie de la Vierge behind the mur de pêcherie the point cloud was first converted to a solid surface by imposing a TIN (triangulated irregular network) mesh over the point cloud. A flat plane was then introduced above the mesh at the height of MSL, MHWN, MHWS and HAT (See Figure 68 & Figure 69 below).

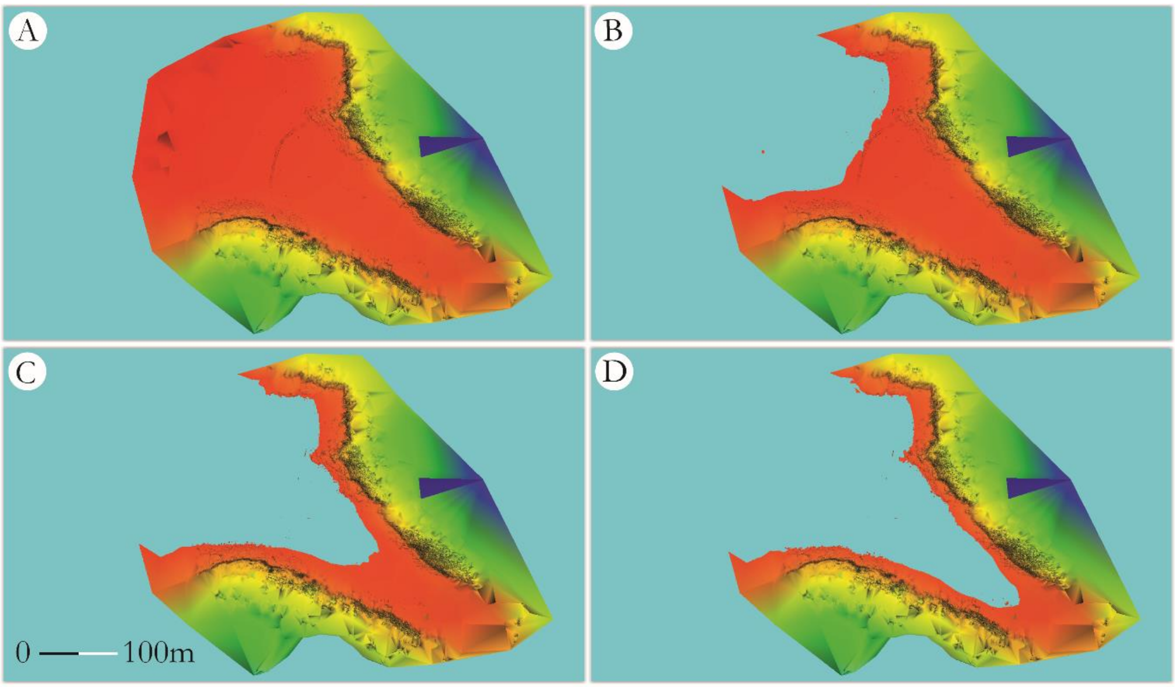

Figure 68 – Plan view of the TIN model generated from the terrestrial laser scanning survey of the structure at le Yaudet. A virtual water level has been calculated to show the relationship of the structure to mean sea level (A), mean high water neap (B), mean high water spring (C) and highest astronomical tide (D).

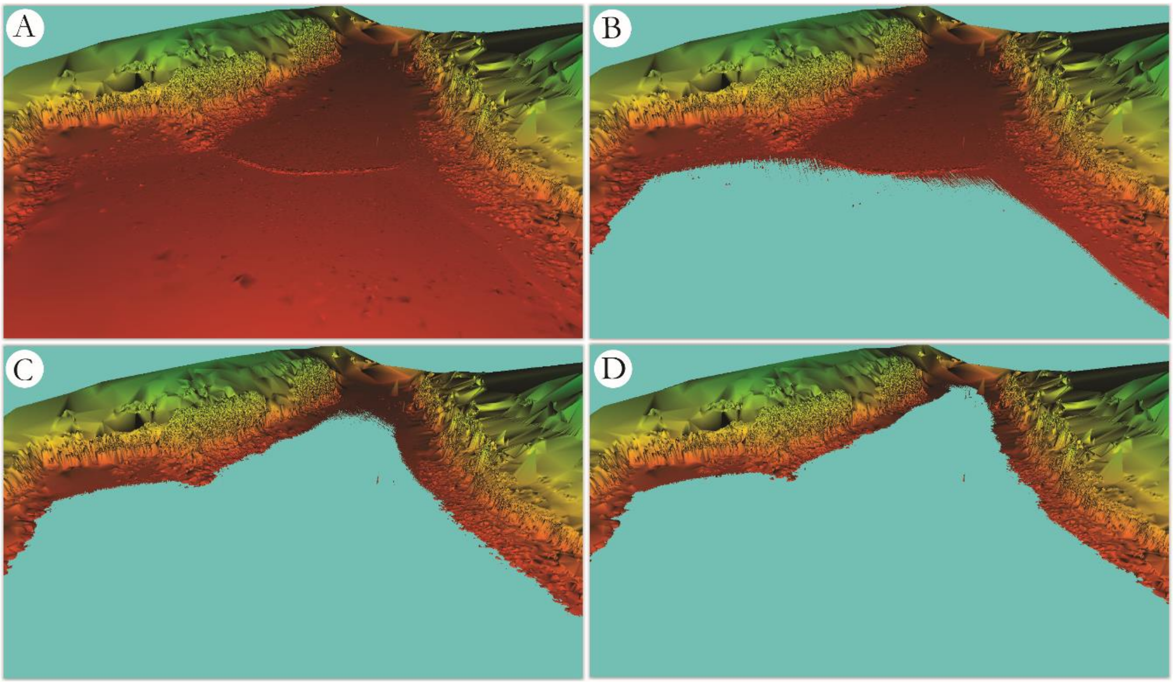

Figure 69 - View from the northeast of the TIN model generated from the terrestrial laser scanning survey of the structure at le Yaudet. A virtual water level has been calculated to show the relationship of the structure to mean sea level (A), mean high water neap (B), mean high water spring (C) and highest astronomical tide (D).

This allows a very effective visualisation of the varying heights of the different tidal states, but also allows for the calculation of the potential of the reservoir by calculating the volume between the plane and the mesh. As noted above, tide mills were unusable on neap tides or when the wind held up the waters, and in any case the MHWN level falls below the level of the structure. A calculation of the volume of the reservoir during MHWS will therefore give the average volume of water on usable tides. This was calculated for the extant remains and then calculated for a range of heights which may represent the extent of the original structure. The excavations by Pinot show that the functional part of the structure lay at least 1m below present ground level, and the lack of a binding course on top of the current structure suggest that it may have been at least one course higher than the current extant remains. Calculations were therefore made for the extant remains and then for the extant remains plus additional heights at 0.5m intervals (Table 11).

	MHWS	HAT
Extant remains	9926.8224237 cu m	26189.6495864 cu m
Extant remains +1m	28177.6647356 cu m	51241.4751587 cu m
Extant remains +1.5m	40253.4508047 cu m	65730.6411528 cu m
Extant remains +2m	53764.6020389 cu m	81210.3379200 cu m

Table 11 - Potential volumetric capacity of the structure at le Yaudet

The volume was then applied to the formula developed by Browne (2007) to calculate the output of the tidal mill and estimate the potential annual output of a tide mill, based on the characteristics of the mill at Nendrum. Although a lot of these characteristics are not clearly known from the site at Léguer, known 7th century AD tide mills show a great deal of consistency. The modern tidal range at Nendrum is *c.*3.4m. The Nendrum millpond has area of 2000m^2, which at MHWS created a volume of water of approximately 1800 cu m. According to Browne (2007) , this allowed the tide mill to generate an annual power equivalent to 50 tonnes of milled barley per year. A preliminary comparison with results of the volumetric analysis at le Yaudet would suggest that the extant remains +1m would have had a volume nearly 16 times greater than that of Nendrum, allowing 800 tonnes of barley to be milled per year.

5.5 The Use of Terrestrial Laser Scanning in Defining the Function of Intertidal Structures

The presumption throughout this chapter has been that the relative sea level and by extension the tidal frame has remained roughly the same since the construction of the various structures within the Léguer estuary. This is a difficult hypothesis to test as an accurate sea level curve does not exist for this location, and in any case would most likely lack the resolution to support this assertion. The tidal gauge at Roscoff has been recording accurate tidal height data since 1973, during which time the monthly mean has risen from mm to mm above RLR (Figure 70).

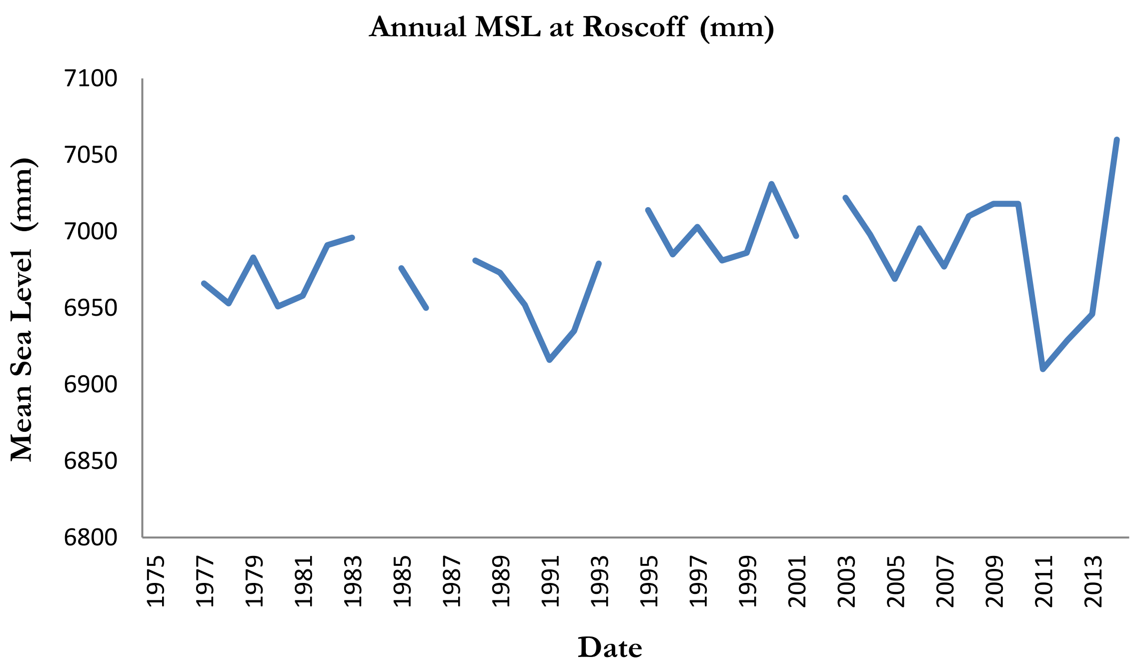

Figure 70 – Fluctations in annual mean sea level at Roscoff since accurate tidal height data in 1973.

However, whilst this represents an upwards progression, this relatively short period accounts for only two full Metonic cycles (the period of 19 years in which the sun, moon and earth return to the same relative positions) so cannot easily be projected backwards over several centuries. It is therefore difficult to use this as a model for the stability of the RSL over past 2000 years at the site. What can be said, however, is that none of the structures at the site lie outside of the tidal frame, all are submerged for at least some of the tides, and none appear to be below LAT. If there had been a significant shift of the relative sea level in either direction one or more of the structures would lie outside the tidal frame. In addition all of the structures are in the right location within the tidal frame to fulfil their original function, all of the presumed fixed fishing structures are situated between the MLWS and MLWN levels, whilst the structure at le Yaudet is perfectly positioned to function as a tide mill. By comparison, examples of fishing structures from other locations in Brittany, as well as comparable sites in Wales and Essex, have been found below the level of LAT. This is indicative of a much more extreme level of sea level change, dating of some of these structures implies that this is not necessarily linked to overall sea level change but to variations in RSL. The proposal by Langouët regarding the dating of structures based on their comparative heights can therefore be dismissed. All of the structures found within the Léguer estuary are still presently within the tidal frame, and all could still be used for the purpose to which they were constructed. The difference in heights between the 7th century timber weir and the later overlying structures appears to have been caused by sedimentation rather than a change in RSL.

As noted above (Section 2.10), independent dating of drystone-built intertidal structures is extremely difficult. The dating of drystone-built fixed fishing structures by association with environmental and archaeological contexts has been proposed (Bowen 1998), and indeed this approach has been used within the Léguer estuary at the structure of le Petit-Taureau, which yielded organic foundations to earlier phases of the stone weir, as well as the earlier timber phase of construction. The use of optically stimulated luminescence (OSL) has also been proposed in such contexts (Mauz *et al.* 2010), however this technique is inherently problematic within the intertidal zone, and crucially does not account for phases of repair or reconstruction. As more reliable dating of sites becomes available it is even more important that the height of structures and the specific features within them is recorded as accurately as possible so that we can begin to map changes across a landscape and start to discuss relative sea level change, changes to the tidal frame, sedimentation and coastal change.

In assessing the function of the varying sites within the Léguer estuary, the application of terrestrial laser scanning can be seen to have made a significant contribution. The use of volumetric analysis of the structure at le Yaudet allows for informed speculation about its potential function. Its morphology, volumetric potential and association with an early monastic settlement all make a strong case for its usage as a tide mill. However, whilst the information adequately illustrates the potential for the site to function as a tide mill, further excavation on the structure at le Yaudet would provide much needed detail on the remaining sluices and potential ancillary structures.

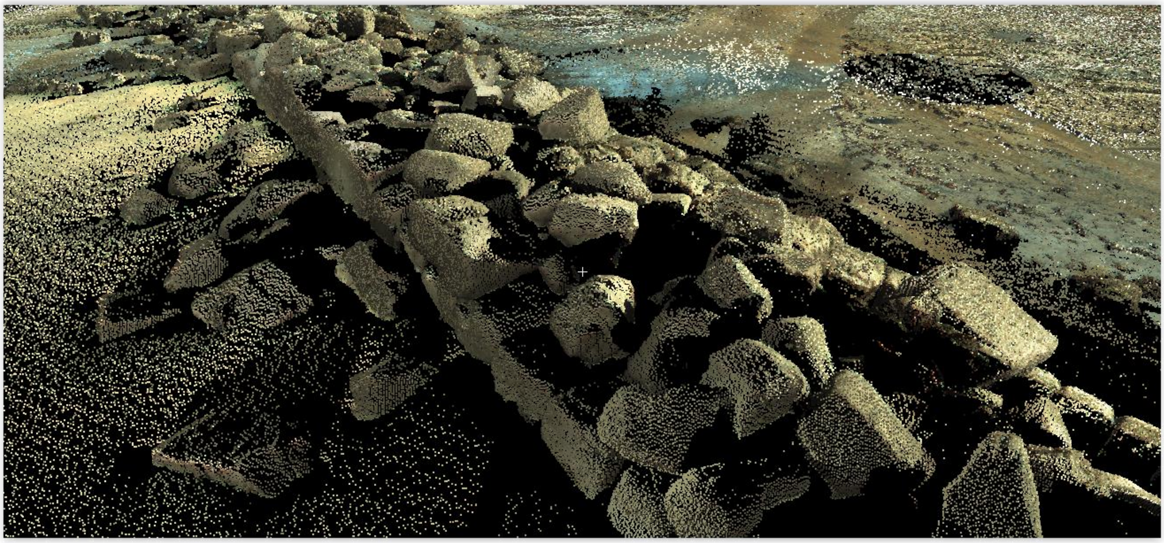

Figure 71 - Terrestrial laser scanning data of the structure at le Yaudet (see Chapter 5). The 'shadows' behind the rocks are voids in the data caused by a lack of survey coverage.

As noted in the introduction to this thesis (Section 1.2), one of the key objectives of this work is to examine intertidal sites using a 'landscape' approach. It is not enough, therefore, to look at only one structure within a landscape within the tidal frame, but rather to examine their comparative associations across the landscape. An examination of the Léguer estuary at a landscape level shows several structures operating for several different purposes across the estuary. It could easily be argued that this exploitation of different parts of the intertidal and coastal zone across the estuary implies a control of the landscape as a whole, most likely from the settlement and probable monastic community at le Yaudet. This would then represent a fortified settlement on a coastal promontory with a sheltered landing place, one large fishweir at le Petit Taureau to exploit the majority of tides, one or more smaller weirs at Dourven and Corps de Garde for the more extreme tides and a tidal mill within the Baie de la Vierge for cereal production. This would certainly be in keeping with the concept of a monastic community; it fits into the early medieval concept of self-sustaining communities with an emphasis on fish-eating, in keeping with the 6th century Rule of St Benedict which also stated that monasteries should have mills (Wikander 2000). The association of the area with 6th century Irish monasticism, with known tide mill sites at Nendrum and Little Island, provides a clear parallel although it could be similarly argued that a secular manorial settlement could possess the same structures.

This case study has shown the value of placing terrestrial laser scanning data within the context of the tidal frame in order to help determine the function and relative chronologies of archaeology sites. Although it could be argued that relating metric survey data to the tidal range does not necessitate the use of terrestrial laser scanning; and that elements of the work in this case study could have been achieved through the use of alternative technologies, the ability to rapidly record a complex structure in a minimal amount of time, provide the necessary detail to accurately place diagnostic elements of this structures within the tidal frame, and provide the resolution necessary to undertake volumetric analysis of landscape features could not have been carried out by any other approach.

Chapter 6: Remote Sensing and Terrestrial Laser Scanning: A Survey of the Foreshore at Emsworth, Hampshire

The poor Britons - there is some good in them after all - they produce an oyster

Sallust 50BC

This chapter will examine the usefulness of augmenting terrestrial laser scanning data with remote sensing imaging technology. In particular, the use of spectroradiometry in the survey of the site at Emsworth, Hampshire will be assessed, and the role of additional imagery in both scientific and representative visualisations discussed. 'Remote sensing' is a broad term used to refer to the gathering of information at a distance. More specifically it refers to technologies that derive information about land and water surfaces from an airborne or orbital perspective, using measurement of reflected or emitted electromagnetic radiation (Campbell and Wynne 2011). Laser scanning, both airborne and terrestrial, is often placed within this bracket as it emits and records the reflection of electromagnetic radiation. However, whilst it is broadly accurate to qualify this as remote sensing, laser scanning's principle function is not the quantification of electromagnetic radiation but its application as a means of measuring and recording topography. By contrast, the majority of remote sensing techniques use the relative reflectance or emittance of electromagnetic radiation from land and sea surfaces to measure or infer differences in material properties. This can involve measurement of the visible spectrum with technologies such as aerial photography, or of parts of the electromagnetic spectrum outside the visible range, using false colour infrared photography and multi- or hyperspectral imaging from airborne or satellite platforms.

Despite primarily recording distance using reflection of an emitted laser, terrestrial laser scanning also records the intensity of the reflected laser signal, allowing for some quantification of material based on comparison of the intensity values (See Section 3.3 above). It is important to state that this value is uncalibrated and remains relative to other values within the same survey rather than representing a definitive measure of a material's reflectance. However, the relative differences between intensity returns should be comparable to differences established with spectroradiometry. A further question that should be asked is whether the detection of such differences is useful in the detection and quantification of intertidal archaeology. Within intertidal archaeology, one of the notable challenges is the difficulty of standard survey approaches in detecting structures composed of organic material against a background of organic sediments and plants. This is problematic for the detection of archaeology in the rapid survey of coasts as remains can be hard to detect with the naked eye or through aerial photography. In particular structures such as oyster pits, which are constructed from wood and designed to contain sediments, are difficult to discern using rapid survey techniques. Two potentially important outputs could be gleaned from analysis of differing intensity returns. Firstly, that terrestrial laser scanning can record features that are not easily discernible from their morphology (i.e. that heavily truncated or buried structures can be identified within sediments) and secondly that features of similar colour to background sediments or organics can be extruded using manipulation of the intensity data. The development of either of these approaches would help to establish terrestrial laser scanning as not only a rapid survey form, but also a potential tool for archaeological prospection. This chapter will assess not only the potential of the technology to integrate with wider remote sensing techniques, but the additional issue of how to integrate external scientific information which does not necessarily have a three dimensional output to terrestrial laser scanning data for the purpose of using the point cloud be used as a database tool.

6.1 Oyster Farming in Chichester Harbour

The oyster industry within Britain is documented from the Roman period, with oysters known to have been shipped from Richborough in Kent in 78 AD (Philpots 1890). Farming of oysters using artificial beds, or lays, is known from the Roman Empire in Pompeii in 95 BC (Mau 2007), so it is possible that oyster production in Britain within this period involved not just the exploitation of natural beds, but a concerted effort to 'farm' oysters. However, little to no research has been done on the early development of the industry within Britain. By the late 12th century AD Domesday records indicate the presence of oyster fisheries in Kent and Sussex (Philpots 1890) but again, this may refer to the legal rights to the fishing of natural beds not to the practice of farming the oysters (Satchell 2011). By 1307 Emsworth oysters were renowned for their flavour (Newell 2011), but again no reference is made to the manner of their production. The first reference to oyster 'pits' in Chichester Harbour dates to 1688 (Satchell 2011), and whilst no archaeological evidence from this date exists to establish the nature of these 'pits', the implication is that some form of artificial reef system was involved (McKee 1967). By the late 19th century A.D., the increasing popularity of Emsworth oysters resulted in their decline due to overfishing of the natural beds, resulting in significant attempts to boost the industry within Chichester harbour. This involved a number of different approaches, including the creation of new private breeding beds, the introduction of the 'French' system of artificial lays made from hurdles covered in crushed oyster shell, and trawling of natural oyster beds from small boats called 'oyster smacks' (Philpots 1890; McKee 1967; Ransley *et al.* 2013). The remains of the pits on Emsworth foreshore represent a storage facility for oysters fished from the harbour prior to their transport by train from Emsworth. The foreshore was organised into a series of pits allowing sorting, storage and cleaning of oysters. The pits were used to keep the shellfish alive and therefore fresh until they were ready for transportation and sale. The Emsworth oyster pits represent part of a much wider infrastructure of oyster production that was of enormous significance to local industry, and had economic impact at a national level.

Figure 72 – Photograph of the oyster pits on the foreshore at Emsworth in 1898 (reproduced in Satchell 2011)

The end of the oyster industry in Emsworth was brought about by the cutting of two drains pushing raw sewage into Chichester Harbour. In November 1902 banquets were held in Winchester and Southampton, at which several guests were poisoned and one, the Dean of Winchester, who had attended both events, died. The resulting inquest ruled that an outbreak of typhoid had been caused by the consumption of Emsworth oysters and their contamination with raw sewage (Satchell 2011). The inquest placed a moratorium on the production of oysters at Emsworth effectively leading to the end of the industry. Attempts to revive it through the late 20th century failed, partially due to further contamination of the oyster beds by high levels of anti-fouling paint used in the leisure boating industry. In the last five years a programme of conservation and regeneration of the oyster fisheries by ecologists has focussed on attempts to reintroduce native oysters (*Ostrea edulis)* to the Harbour, as these had been largely replaced by Pacific oysters (*Crassostrea gigas*) introduced in the 20th century in an attempt to revive stocks (Inshore Fisheries and Conservation Authority 2014). Whilst there is little chance that oyster farming will return to Emsworth, however, interest in the history of the industry and the part that it played in both the local and national economies has increased in the past decade, culminating in an HLF funded research project which resulted an exhibition at Emsworth museum and an associated publication (see Newell 2011), and the restoration of the 19th century oyster smack *Terror*. Concern that the Emsworth oyster pits were being affected by an increase in erosion within the harbour led to a survey of the area by Chichester District Archaeology Society and Maritime Archaeology (Satchell 2011).

Figure 73 – The oyster pits on the foreshore at Emsworth at mid-tide looking south

The pits on the foreshore at Emsworth represent the remains of a short-lived and highly specialised industry, with strong parallels to the site at Aust (See Chapter 4Chapter 4:), and representative of the wider late-19th century specialisation in fishing industries (Fox 2001). Such sites are important not only in developing the ecological and piscicultural landscape of the area, but in understanding the local economic and cultural development of the area. The threat to these sites is not merely a loss of historic material but a loss of potential insight into an under-researched and poorly understood socio-economic phenomenon.

6.2 Remote sensing and intertidal archaeology

The need for rapid evaluation of the intertidal and coastal zone has inevitably led to the adoption of airborne technologies to cover large areas of coast as efficiently as possible. The different forms of aerial remote sensing techniques applied rely on measuring various forms of reflectance. At the most basic level this involves the use of photographic technologies. Aerial photography in both the visible and infrared ranges has been extensively used in the mapping and detection of archaeological remains within intertidal and coastal archaeology, and has formed the backbone of national mapping programmes and rapid coastal zone assessment (English Heritage 2007; Dawson and Winterbottom 2003). In addition technologies such as multispectral and hyperspectral imagery have been applied from both airborne and satellite platforms, providing the ability to analyse the landscape at a range of different scales and resolutions (See Figure 29 above). The development of low level remote sensing through the use of UAVs raises the possibility of applying techniques at a site based level, which due to the lower altitudes and speeds of the UAVs have the potential to record structures at a much higher resolution.

A number of problems exist in the application of remote sensing to the survey of coastal and intertidal archaeology sites. Firstly, a key restriction of remote sensing approaches is that they are mainly airborne, and thus more subject to atmospheric limitations such as fog and low light levels. As with all intertidal surveys, airborne remote sensing techniques must also be timed to coincide with low tides in order to actually detect the archaeology. Although bathymetric airborne laser scanning exists it is not of a suitably high accuracy or resolution to detect archaeological structures or sites below the water. Resolution of airborne remote sensing technologies is highly important in detecting the presence of archaeological structures. As was demonstrated at Aust (See Chapter 4 above), airborne laser scanning failed to detect the putcher rank, despite a relatively high resolution survey of the site. Any technology employed in rapid assessment needs both to the ability to discern features from backgrounds of similar colour and material, as well as being able to achieve the level of detail to detect very subtle structures. One of the main difficulties in identifying intertidal sites at any level is their obfuscation by sediment or vegetation, and this is particularly so with remote sensing techniques, which lack the ability to check the data in the field. These problems do not rule out the use of airborne remote sensing, but any approach which seeks to apply the technology must understand the limitations both of the technology and its application.

A trawl of readily available data sets shows that the foreshore at Emsworth has previously been mapped using a range of remote sensing techniques. Available data includes aerial orthophotography and false colour infra-red (FCIR) photography, airborne laser scanning and satellite imagery.

Figure 74 – Aerial photo of the foreshore at Emsworth showing the outline of the oyster pits demarcated by the growth of bladder wrack on the remains of the structures (© Channel Coastal Observatory)

Both aerial orthophotography and aerial false colour infra-red (FCIR) imagery exist for the foreshore at Emsworth (Figure 74 & Figure 75), and shows the outline of the oyster pits on the foreshore. However, closer inspection reveals that the differences in colour are in fact due to the presence of bladder wrack (*Fucus vesiculosus*) growing on the projecting timbers of the oyster pits, rather than representing the timbers themselves. This highlights a common issue in the identification of intertidal structures, in that projecting or hard elements of their composition become footings for the growth of intertidal plants and shellfish. In the case of the site at Emsworth the orthogonal layout of the structures means that the vegetation emphasises the outline of the oyster pits, but in many other situations, the growth of seaweeds serves to obscure the archaeological remains. This has important implications for the use of remote sensing within the intertidal zone as the technology relies on the reflectance values of the surface material, rather than structures which may be obscured.

Airborne laser scanning of the foreshore at Emsworth was carried out by the Environment Agency in September 2013, at a resolution of 1 point per metre (see Figure 76). Despite this relatively low resolution, the outlines of the oyster pits are nevertheless visible. A higher resolution survey or the application of low level UAV based aerial laser scanning would pick out significantly more detail.

Figure 75 – False-colour infrared imagery of the foreshore at Emsworth (© Channel Coastal Observatory)

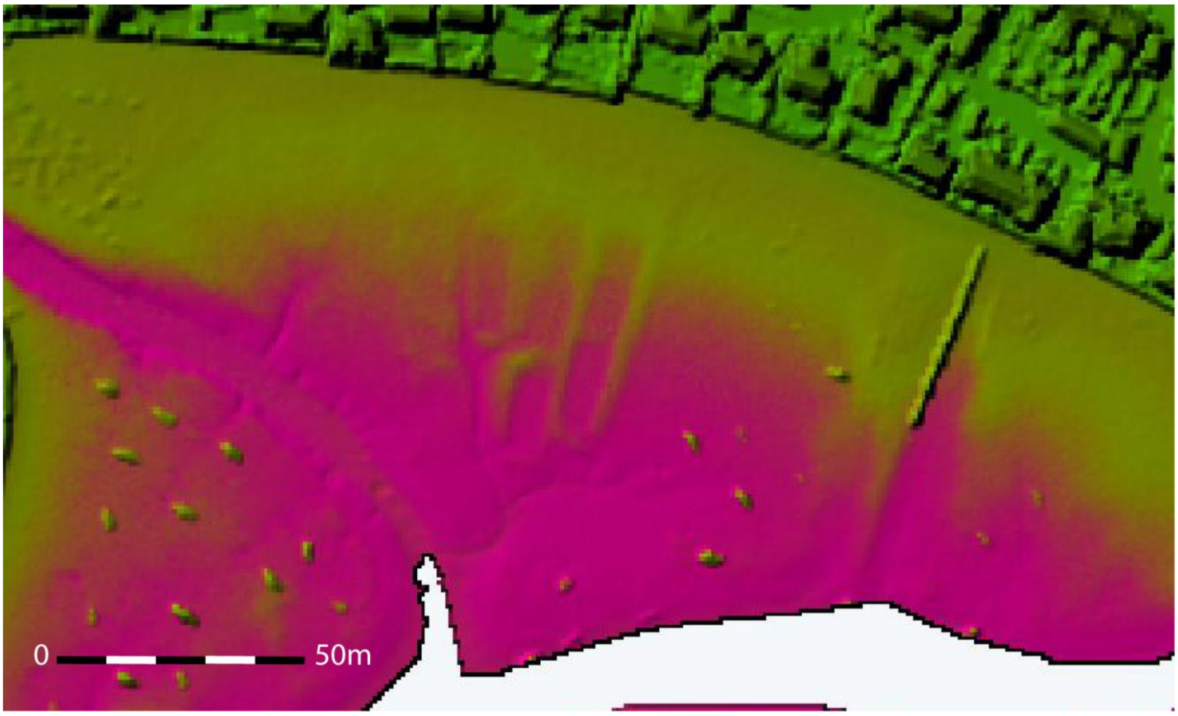

Figure 76 - Airborne laser scanning data from 2013 showing the foreshore at Emsworth (© Channel Coastal Observatory)

The use of satellite based remote sensing has also been trialled on the Emsworth foreshore as part of an English Heritage pilot project which aimed to use multispectral satellite imagery as a means of detecting intertidal archaeology (Burningham *et al.* 2011). Quickbird multispectral satellite imagery of known archaeology sites within Portsmouth and Langstone Harbours was used to establish a base reference and then compared to the results throughout the harbours in an attempt to identify new sites. However, the level of resolution from the satellite imagery was found to be insufficiently high to identify features. Even if sufficient resolution had been achieved, the reliance on responses from known archaeology sites would limit the approach to areas where sites are already known to exist, restricting the use of the technique as a prospection tool.

The potential for integration of terrestrial laser scanning data with forms of remote sensing imaging has been demonstrated in geological applications, where readings from a hyperspectral camera were draped over the topographic information provided by terrestrial laser scanning to

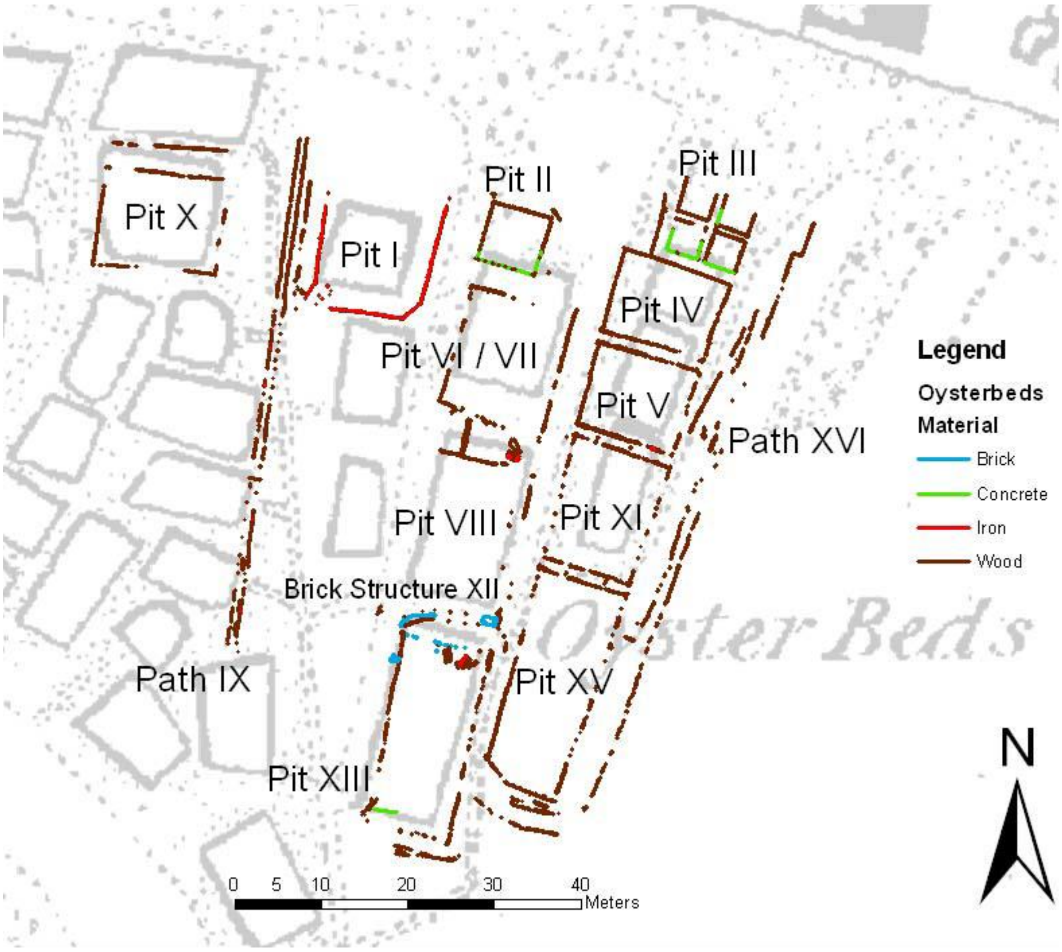

Figure 77 – The results of the 2008 survey of the Emsworth oyster pits carried out by Hampshire and Wight Trust for Maritime Archaeology overlain on the 1st edition Ordnance Survey map of the area (Satchell 2011).

accurately map the locations of different deposits (Taylor and Nieto 2012). Whilst such an approach has obvious parallels with the mapping of archaeological remains, one major issue is that the approach involves the mapping of imagery over largely planar surfaces, often from a single setup, rather than complex three dimensional shapes. This case study is not an attempt to fully integrate the two technologies, as this would require specific equipment unavailable for the purposes of this study; rather it is a comparison of the two techniques to allow some basic conclusions can be drawn. In essence the approach is using ground based technology to mimic the results from aerial technology. This has the advantage of being logistically easier and less expensive, but also allows for the data to be validated on site.

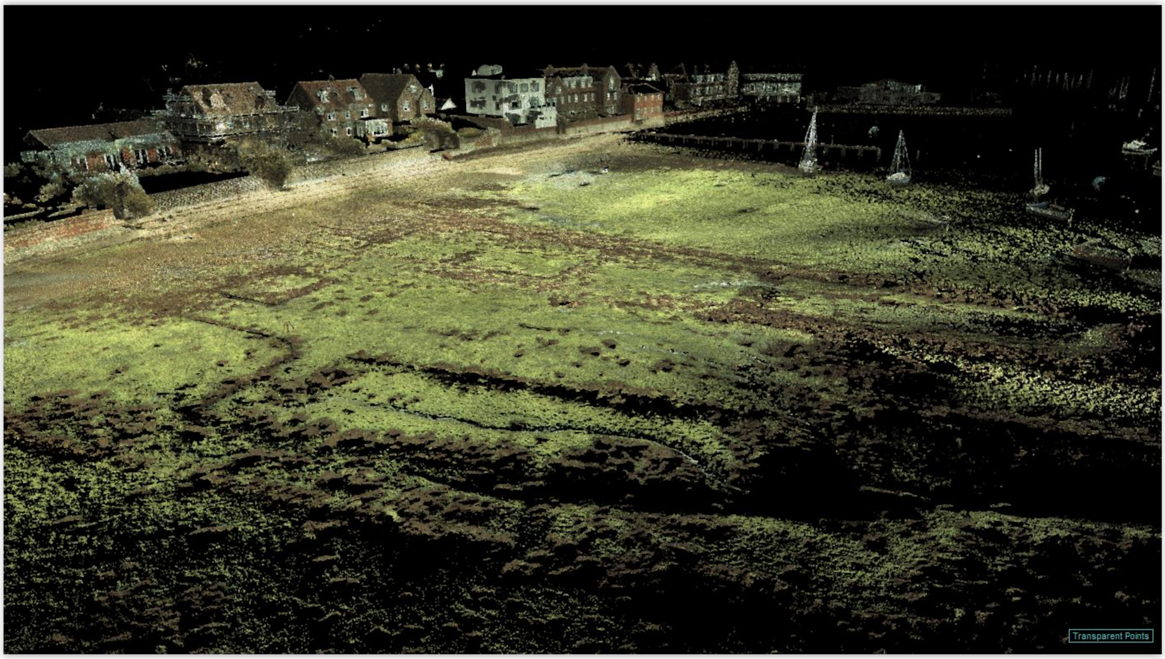

Figure 78 – Screengrab showing the results of the terrestrial laser scanning survey on the foreshore at Emsworth viewed from the west

The site at Emsworth was selected for several reasons. Firstly, it is located at the high end of the tidal range in Chichester Harbour, with easy access to the foreshore allowing all of the equipment to be transported to site. In addition the site had already been surveyed by Maritime Archaeology and CDAS in 2008 (Figure 77), meaning that the extents of the site were already known and that ground control was already in place. This had the advantage of maximising the time available on site to trial the technology. The foreshore at Emsworth also provides a range of different material types for analysis, with both soft silt and shingle sediments, and a range of vegetative cover. The structures are mainly composed of wood, with elements of brick and concrete added at later dates. As the survey was carried out in September, a number of the pits were under varying degrees of vegetative cover. Some parts of the timber structures were evident but most were obscured by a heavy growth of bladder wrack (*Fucus vesiculosus*), which had attached to the exposed structures. Due to their similarities to rock pools, the interiors of the pits were mainly obscured by gutweed (*Ulva intestinalis*). The terrestrial laser scanning survey of the site at Emsworth was carried out using a Leica ScanStation C10. The scanner was set up in eleven different locations around the main line of oyster pits, from Pit III to Pit XV (See Figure 77 above), and recorded the site at an overall point spacing of ≤2mm. The survey took approximately 3.5 hours to complete, equivalent to the amount of time that the oyster pits were fully exposed by the tide.

Equipment Used	Positional Accuracy
Leica ScanStation C10 TLS	±6mm
Leica GS09 GNSS	±20mm
Registration Error	±2mm
Cumulative Uncertainty	**±28mm**

Table 12 - Cumulative uncertainty in the survey at Emsworth

The spectroradiometry survey was carried out the following day using an SVC HR-1024i spectroradiometer capable of measuring wavelengths between 350-2500 nm. The instrument was fitted with a lens with a 4° field of view, meaning that when positioned over a point, the overall area of material being measured was approximately 10mm. The instrument was mounted on a tripod and pointed directly downwards, and readings were taken at intervals every five metres across the site. The readings were calibrated using a reference panel from which a reading was taken prior to every three measurements. The aim of the spectroradiometry survey was to build up a series of readings on different deposits and materials, and compare the reflectance to the intensity data from the laser scanning. The readings from the field spectroradiometer should in theory simulate the results of satellite sensor data and enable comparison between what a satellite and a terrestrial laser scanner would record.

6.3 Spectroradiometry and terrestrial laser scanning

The spectroradiometry survey of the foreshore at Emsworth was carried out using a Spectra Vista Corporation HR-1024i spectroradiometer, capable of recording wavelengths between 350-2500nm. The results from the spectroradiometry survey were processed using the Spectra Vista software and exported to Microsoft Excel. The reflectance value for the wavelength of 532nm was exported from each of the materials and the results compared to the intensity returns from the scanner. As the spectroradiometer averages the reflectance of the material from within its field of view, it was decided to do the same with the results from the intensity returns. Areas covered by the spectroradiometer were selected from the point cloud data and the points exported in .pts format. This allowed the data to be imported into Excel and the intensity returns for that area to be selected and averaged. A comparison of the results is shown in Table 13.

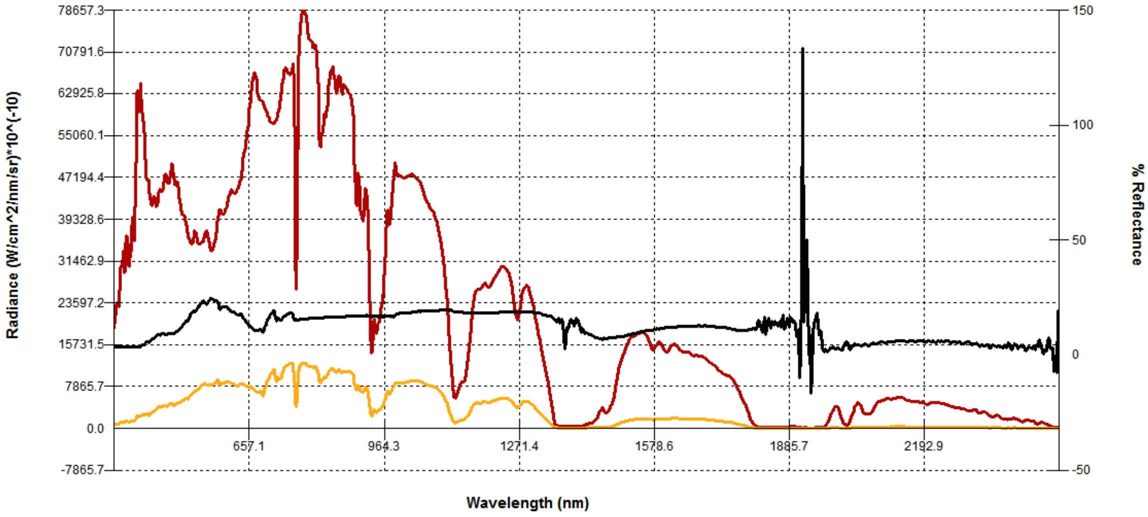

Figure 79 - Example of spectroradiometry reading from Emsworth foreshore. The reference data (red) is used to calibrate the target data (yellow) to provide a finalised reflectance reading (black). The extreme peak on the reflectance data is caused by the overlap of sensors within the equipment.

It is important to note that the terrestrial laser scanner measures only the reflectance of the laser which it produces, which has a wavelength of 532nm, and records the relative reflectance of the returning signal on a scale that differs from instrument to instrument. There appears to be no way of quantifying this value outside of the relative numbers which the scanner applies. By contrast, the spectroradiometer records reflectance in a range of wavelengths from 350-2500nm and uses an external calibration system to provide quantifiable values for the reflectance in each wavelength. There is a discernible difference between the reflectance from different materials using both technologies, but there is no clear method of establishing a quantifiable relationship between them.

Material	TLS Intensity Returns	Spectroradiometry Absolute Reflectance
Shingle	-1372.93426	5.37
Bladder wrack	-1412.6677	2.43
Gutweed	-1409.0923	25.37
Timber	-1362.9300	19.72

Table 13 - Comparison of reflectance values recorded by terrestrial laser scanner and spectroradiometer of material on Emsworth foreshore.

The approach can be criticised on a number of levels. Firstly, the two technologies are radically different in the way they operate. Terrestrial laser scanning is an active system, meaning that it emits as well as records a beam, whilst spectroradiometry is a passive system, measuring only the reflectance of external radiation. Whilst the individual readings from the spectroradiometer are calibrated by means of a plate to validate the results, terrestrial laser scanning has no such facility, meaning that changes in intensity can be as much about battery power as they can material properties. In addition, the intensity returns from terrestrial laser scanning are influenced by a range of variable factors such as angle of incidence, distance to target, atmospheric conditions and the individual characteristics of each scanner. Averaging the results from the terrestrial laser scanning survey can in part address this issue, but the results are by no means accurate or repeatable. Thirdly, by necessity the two different surveys took place on two separate days, due to the limiting factors of time and tide. Increased manpower may have helped to account for this, but there are limiting factors in the use of spectroradiometry which had to be taken into consideration. A constant level of light is required, with no clouds within a 10° angle of the sun, and can only occur during the central part of the day. As with all intertidal survey, this must also coincide with the optimum part of the tidal frame. The necessity for good weather means that survey is limited to a time of year when vegetative cover is at its highest. This means that more of the archaeological remains are obscured than during the winter months. The application of the technology to intertidal technology in Britain is therefore extremely challenging.

One of the key issues raised is the means of directly comparing the results in a visual manner. Unlike the work of Taylor and Nieto (2012), the data from the spectroradiometer cannot be directly draped over the point cloud, so for the data to be visualised spatially a different method of linking the datasets must be used. To achieve this, the dataset from Emsworth was exported from Leica Cyclone as a TruView dataset. Leica TruView is an html based platform which allows the viewing and manipulation of point clouds. The geographic location of each of the spectroradiometry readings was then entered into the database as a point, and the data and metadata from the spectroradiometry hyperlinked to that location. The premise was that many different forms of information exist that have little spatial value, but which increase in benefit through being visualised in a spatial manner. In addition the notion of rapidly recording threatened coastal archaeology sites demands that sites are recorded in many cases without a full understanding of the nature of the archaeology. The ability to share information virtually, and provide forums for comment, could allow for the contribution by specialists on different types of site remotely, and also permit the long term building of datasets by community groups. This type of approach is essential for the future of coastal zone survey and monitoring, which is increasingly being carried through at a community outreach model, through initiatives such as the Thames Discovery Project or the Coastal and Intertidal Zone Archaeological Network (CITiZAN). The use of ArcGIS is one way to access this information (See Chapter 4) but is better employed at a landscape rather than a site level and does not allow for complex three dimensional shapes or for hosting a large amount of data online. Platforms such as Leica

Truview allow for basic manipulation of the point cloud, the ability to attach additional forms of information through hyperlinking, and crucially, the ability to attach and respond to comments, allowing for a virtual discussion of the archaeology.

6.4 Reflecting on the foreshore

Both terrestrial laser scanning and spectroradiometry can be used to distinguish the difference between different material types on the foreshore through comparison of reflectance values. However, the attempt to establish a quantifiable link between the two types of data is not straightforward. This is mainly due to the fact that terrestrial laser scanning was not designed to measure reflectance, but instead produces scaled intensity returns on relative scale for the purpose of simple visualisation. The intensity values of the returning laser signal from the terrestrial laser scanner did not show enough difference between material types to advocate its use as a prospection tool; it showed good potential for identifying radically different materials but failed to adequately distinguish between different forms of organics or the highly mixed materials on the foreshore. Despite the problems encountered through the above approaches, remote sensing shows the potential to be adapted for archaeological prospection in the intertidal zone, but questions must be raised over the validity of such an approach. Within this case study, the approach used was ground based, but designed to mimic an airborne platform. Whilst it was designed to trial the concept, the premise of using the equipment was to evaluate a more rapid means of surveying intertidal archaeology sites. The difficulty in transferring this approach to an airborne system is in achieving the necessary resolution to be of use. There is the potential that a low-level UAV survey could provide a higher level of resolution, but currently the spectroscopy equipment has too large a payload to be supported in such a way. One of the key limitations of remote sensing technology is that it relies on reflectance of surface properties. As the site at Emsworth has shown, the nature of intertidal structures means that they often obscured by plant and shellfish growth. Likewise the site at Aust (Chapter 4) was covered by wrack, whilst the sites at Léguer (Chapter 5) and Selsey Bill (Chapter 7) were colonised by barnacles and shellfish. The potential use of remote sensing technologies as a means of prospection for archaeology sites within the intertidal zone must therefore account for the obfuscation of structures by organic growth as well as burial by sediment.

Logistically there were challenges involved in deploying this approach in the field. The equipment was not easily portable or manoeuvrable especially on uneven ground surfaces, meaning that the approach was in no way rapid. Attempting to carry out both the spectroradiometer and terrestrial laser scanning surveys in one day proved impossible, and additional manpower would only have created obstacles for both forms of survey, which required the site to be as clear as possible. Consequently the surveys were carried out on two different tides, which raised difficulties in the comparison of results due to the rapidly changing nature of the foreshore.

The logistical challenges in using the kit in the field by far outweighed any positive data provided. The type of information did not easily compare or integrate with terrestrial laser scanning, and is not a good approach for the detection of, or prospection for, intertidal archaeology sites. The same criticism can be levelled at remote sensing as can be levelled at aerial photography in its use in the intertidal zone, that it cannot reliably discern archaeology through vegetation or against background organics, and that it fails to achieve the level of resolution necessary to record sites. Ground based approaches can overcome some of these obstacles but if sites are accessible on the ground then much better methods of investigation are available. In short, the use of this form technology either individually or in combination with other technologies is the wrong approach.

What did succeed within this case study was the use of the point cloud as a means of affixing and sharing additional information about the site. The use of Leica TruView enables the display and interrogation of the dataset, unlike the application of GIS to such environments (see chapter 4) it can handle complex three dimensional shapes, and allows for the display of data in both RGB and intensity scales. More importantly it allows for sharing of different forms of information that cannot be easily integrated, and for the development of forum and comment on rapidly recorded threatened archaeology sites.

Chapter 7: Reclaiming Past Landscapes: Excavation and Terrestrial Laser Scanning at Selsey Bill, West Sussex

For the bishop, when he came into the province, and found so great misery from famine there, taught them to get their food by fishing; for their sea and rivers abounded in fish, but the people had no skill to take any of them, except eels alone.

Bishop Wilfrid converts the South Saxons at Selsey, Bede Chapter XIII

Between 2010 and 2013 the Environment Agency (EA) undertook a major programme of works to construct a new flood defence on the western side of Selsey Bill, West Sussex entitled the Medmerry Managed Realignment. In advance of the works archaeological investigations were carried out by Archaeology South-East (ASE) revealing a series of linear wooden structures dating from the Late Saxon to the earlier post-medieval period located in an area of drained coastal marsh. The largest of these structures, dating to the late 14^{th}/early 15th century AD, was partially excavated in advance of the construction of a large borrow pit, affording an opportunity to record sections of a wattle-built structure excavated within the constraints of a commercial archaeology site, and to develop a methodology for incorporating TLS survey into the workflow of coastal wetland archaeology excavation. Here the results of the survey are compared to traditional archaeological recording carried out on site and the relative merits of the two recording systems is discussed. The TLS data will also be integrated with the results of geoarchaeological analysis of the surrounding deposits to propose an interpretation for the function of the structure, which was unknown at the time of excavation. The importance of understanding such structures prior to destruction in the context of their original landscape will be highlighted, and the necessity of a multi-disciplinary approach to such landscapes emphasised.

7.1 Reclamation and Realignment: Changing Landscapes on Selsey Bill

The Medmerry Managed Realignment Scheme is located on the west side of Selsey Bill. Within the scheme the specific site covered by this study is approximately at the location formerly occupied by Medmerry Farm (Figure 80). In order to understand the context of the site, its potential purpose and the need for an integrated and detailed archaeological approach, it is worth briefly considering the landscape history of the area.

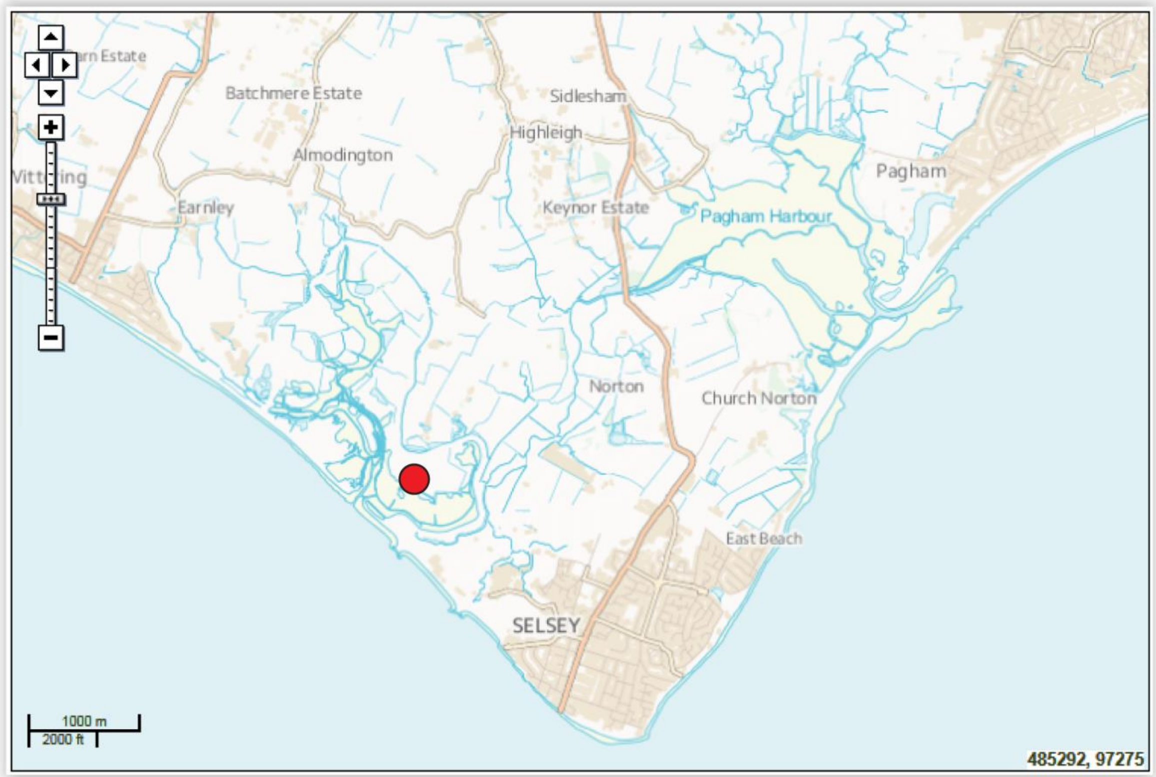

Figure 80 - Map of Selsey Bill, West Sussex showing the outline of water courses on the promontory (© Environment Agency). Site location is marked by a red dot.

Selsey Bill has been a focus for geological study since the early 19th century owing to the presence of the fossil rich Bracklehsam Beds, glacial erratics and raised beaches (Bone 1996; Castleden *et al.* 1996), and in particular is connected with the work of Edward Heron-Allen a prominent local geologist and antiquarian. However, whilst there has been a lot of focus on the geology of the area, there has been relatively little research on the changing landscape of the Bill during the late Holocene.

Selsey Bill is a prominent triangular headland on the south coast of West Sussex, which marks the widest part of the coastal plain. There has been a large amount of speculation about the original extent of Selsey Bill, which is known to have suffered from extensive erosion within the past few centuries, a process that has continued to the present day. The erosion is associated with bars of shingle that move eastwards along the Sussex coast. On the east side of Selsey Bill is Pagham Harbour, a tidal inlet that represents the last vestiges of a tidal strait running across the entirety of Selsey Bill, cutting it off from the mainland. (Castleden *et al.* 1996). The remains of this channel can also be seen in the large number of watercourses or 'rifes' which help to drain the western side of the Bill. Research on the landscape history of Selsey Bill has been dominated by two prominent and highly eccentric figures, Edward Heron-Allen, who as well as being a geologist and antiquarian, was a notable violin-maker, scout-master and science fiction writer, and Major Hume-Wallace, a diver and amateur archaeologist who speculated the existence of Roman Harbours as far out as the Mixon reef formation. Heron-Allen's work is still viewed as the seminal work on the development of Selsey Bill, whilst the views of Hume-Wallace have mostly been discredited (Bone 1996), but continue to influence the debate.

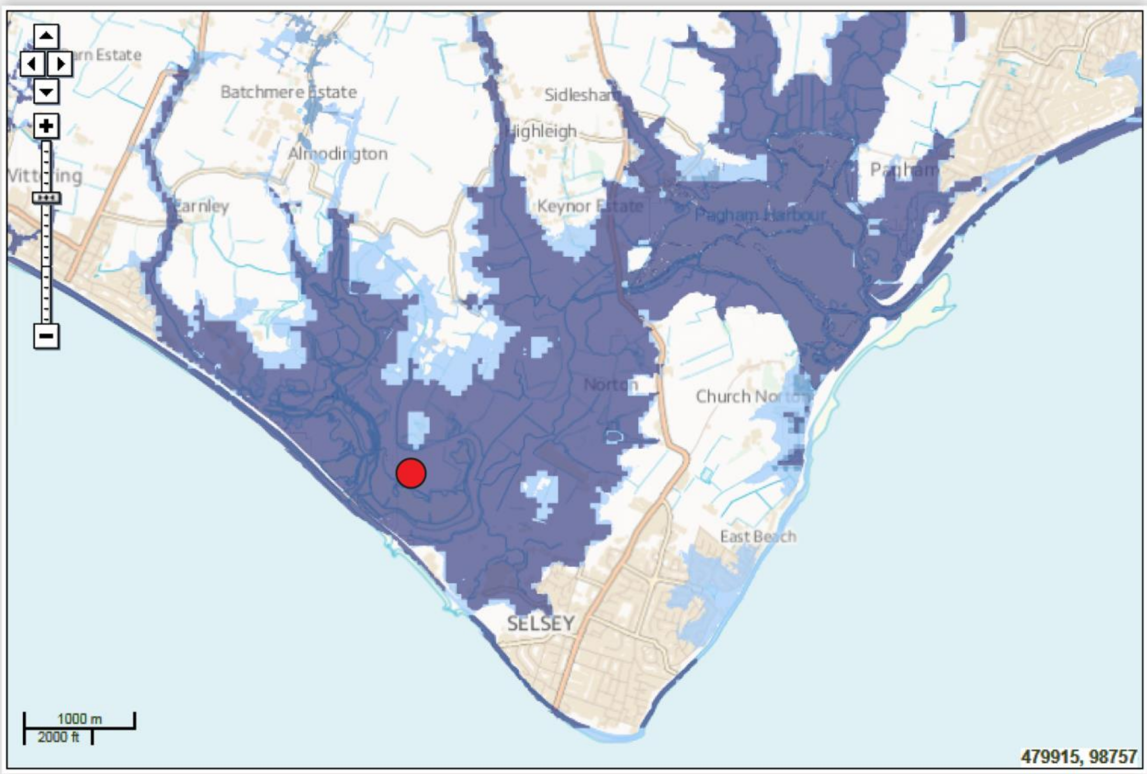

Figure 81 - Flood Risk Map highlighting areas of low-lying land surrounding water courses on Selsey Bill (© Environment Agency). The site location is marked by a red dot.

The low-lying land on Selsey Bill is highlighted by the Environment Agency's flood risk map for the area (Figure 81) which shows the low-lying areas next to the numerous water courses in the area. A comparison with the underlying geology of the Bill (Figure 82) shows the clear correlation of the low-lying areas with raised marine deposits.

Historically the medieval and post-medieval geography of Selsey Bill is very well documented, in part owing to its importance as an ecclesiastical site from the 6th century AD onwards (see quote at the beginning of the chapter). A monastery was established near Selsey in the 7th century AD by St Wilfrid, most likely at the site of Church Norton, and became the centre of the Diocese of Selsey, which was later relocated to Chichester in the 11th century AD. Bede's *Ecclesiastical History of England* explicitly refers to the geography of the area:

> *The place is called Selaeseu, (Selsey, south of Chichester) that is, the Island of the Sea-Calf; it is encompassed by the sea on all sides, except the west, where is an entrance about the cast of a sling in width; which sort of place is by the Latins called a peninsula, by the Greeks, a cherronesos.*

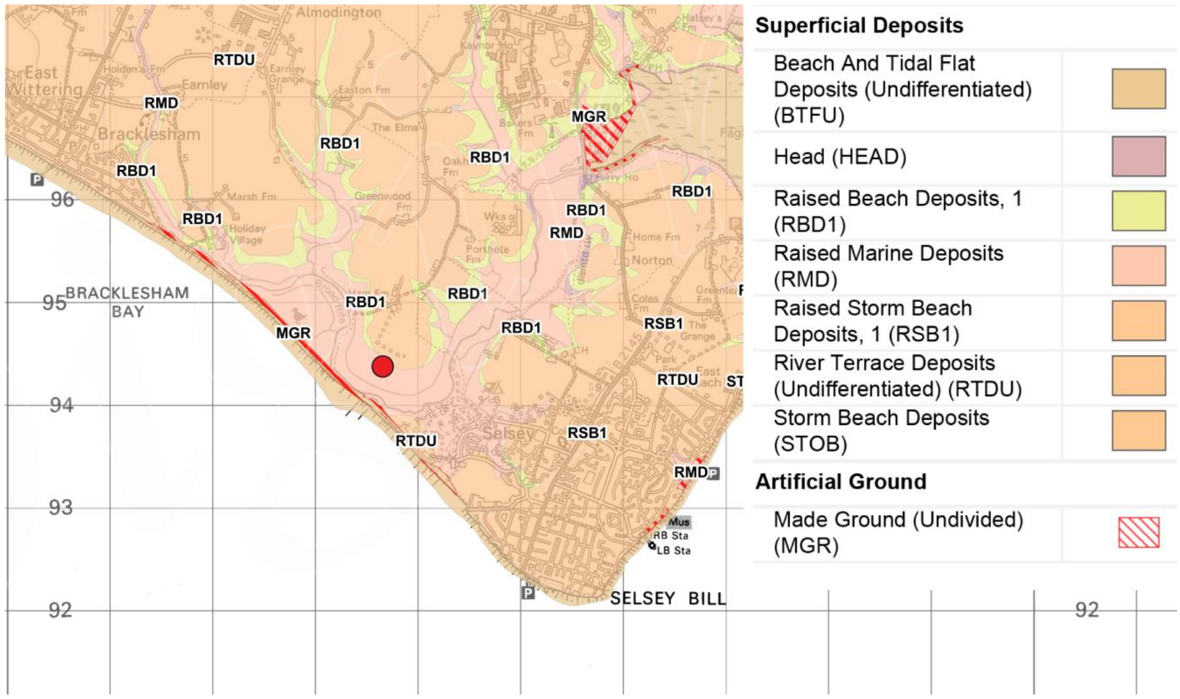

Figure 82 – Map of the underlying geology of Selsey Bill. Site location is marked in red.

Medmerry itself means 'medium island' (Bone 1996), and place-names surrounding the site such as 'Thorney' and 'Earnley' likewise bear the Anglo-Saxon suffix '-ey' denoting an island. Rather than forming an archipelago these appear to have been islands within a coastal marshland. The area of Ham to the north of the site is referred to as 'hamme' in the earliest documentary sources, meaning 'land hemmed in by water or marsh; a river-meadow; cultivated plot on the edge of woodland or moor' (University of Nottingham 2015). The place name evidence for the area therefore gives the impression of a range of settled areas of higher ground within a coastal marshland or fen. By the 13th century AD a large amount of drainage is known to have taken place to the west of the site across Chichester harbour and to the east of the site on lowland areas of Selsey Bill, most likely in the 'heyday' of medieval reclamation which began directly after the Norman Conquest in the 11th century AD and peaked during the 12th and 13th centuries AD (Galloway 2013). The drive to reclaim land for agricultural purposes reflects the high value of the resultant ground which was extremely fertile, in some cases having a value of up to one and a half times that of the adjacent dryland (Rippon 2000). The 13th- 15th centuries AD saw an increased period of storminess along the south and east coasts of Britain, with well documented flood events occurring during the winter periods (Brown *et al.* 1998). Numerous documentary sources throughout this period refer to the destruction of tide mills, the silting of harbours and the destruction of entire coastal towns, such as Winchelsea and Dunwich, due to enhanced coastal erosion and flooding of the coastal belt. The *Nonarum Inquisitiones*, set up during this period to assess the damage caused by such storms to the agriculture of Sussex records that

4,000 acres of arable land had been lost to flooding, with 2,700 in the parish of Pagham on the east side of Selsey Bill (Baker 1966). The exceptionally large loss of land in this area could be due either to coastal erosion or to the flooding of reclaimed land at the east end of Pagham Harbour, and it is unclear how permanent the loss of this land was (Brandon 1971).

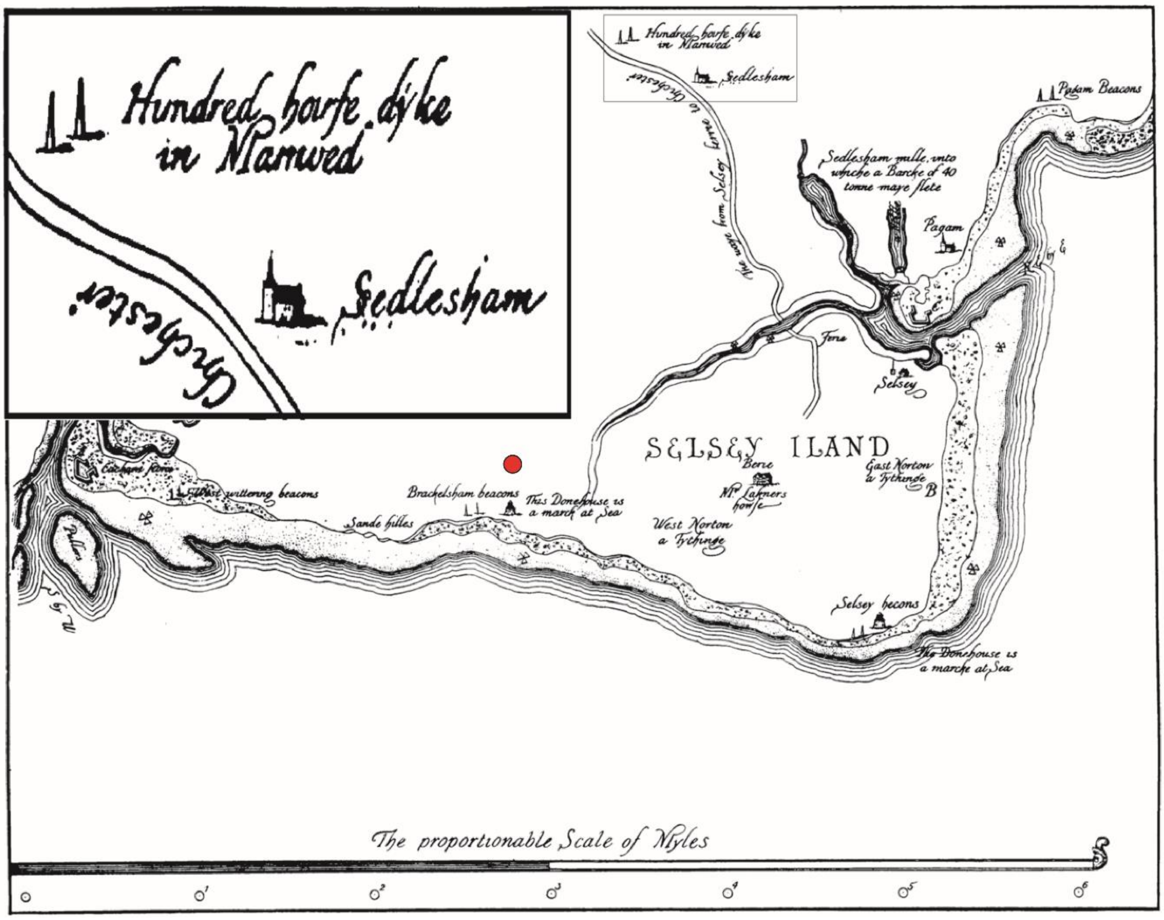

Figure 83 – The 1587 Armada map of Selsey Bill (reproduced in Heron-Allen 1911). The approximate location of the site is marked with a red dot.

The first accurate map of the area was produced in 1587 as part of the 'Armada' survey of British ports (Figure 83), and refers to 'Wytering Harbour' (an earlier name for Pagham Harbour) as being accessible to ship of up to 40 tonnes, far in excess of its current capacity.

Figure 84 - Detail of the Yeakell and Gardner map of 1778-1783 (University of Portsmouth 2016). Note 'Ham Marsh' and 'Medmerry Marsh' on the west side of the Bill, as well as the clear siltation of the marshland heading from west to east. The site location is marked with a red dot.

The Yeakell and Gardner map of 1778-83 (Figure 84) is incredibly useful in helping to understand the more recent landscape history of the area, as it shows the midpoint of the slow drainage of the marshland on Selsey Bill. The west side of the area, including the site of Medmerry is clearly demarcated as marsh, marking the west side of the former tidal strait. Broad Rife can be seen draining into Pagham Harbour to the east, which can be seen in its near current configuration. The transformation of this area appears to have been driven not by anthropogenic factors but by the natural separation of the strait at the west end, leading to the slow siltation from west to east. This separation appears to have been driven by the banking of shingle up against the west side of the Bill, a process echoed in the blocking of Broad Rife and Earnley Rife in the 19th century. The siltation of the landscape from west to east appears to be driven by coastal barrier development in the long shore drift direction. This slow silting of the harbour network is part of a wider coastal pattern in Sussex, involving the growth of shingle spits at the mouths of rivers and harbours impeding drainage and encouraging the eastern movement of river mouths and the silting up of harbours and estuaries. This process enabled the reclamation of marshland at Selsey to take place with a minimum of human intervention having been largely environmentally driven, but exploited and encouraged by landholders. The 19th century saw the reclamation of the remaining portion of Pagham Harbour, again a semi-natural process which involved allowing the moving banks of shingle to bar the entrance. This area of reclaimed land was eventually abandoned due in part to large storms in the early 20th century, which overwhelmed the sea walls and returned tracts of Pagham Harbour to its original state. From the early 20th century onwards the mouth of the inlet has been kept clear.

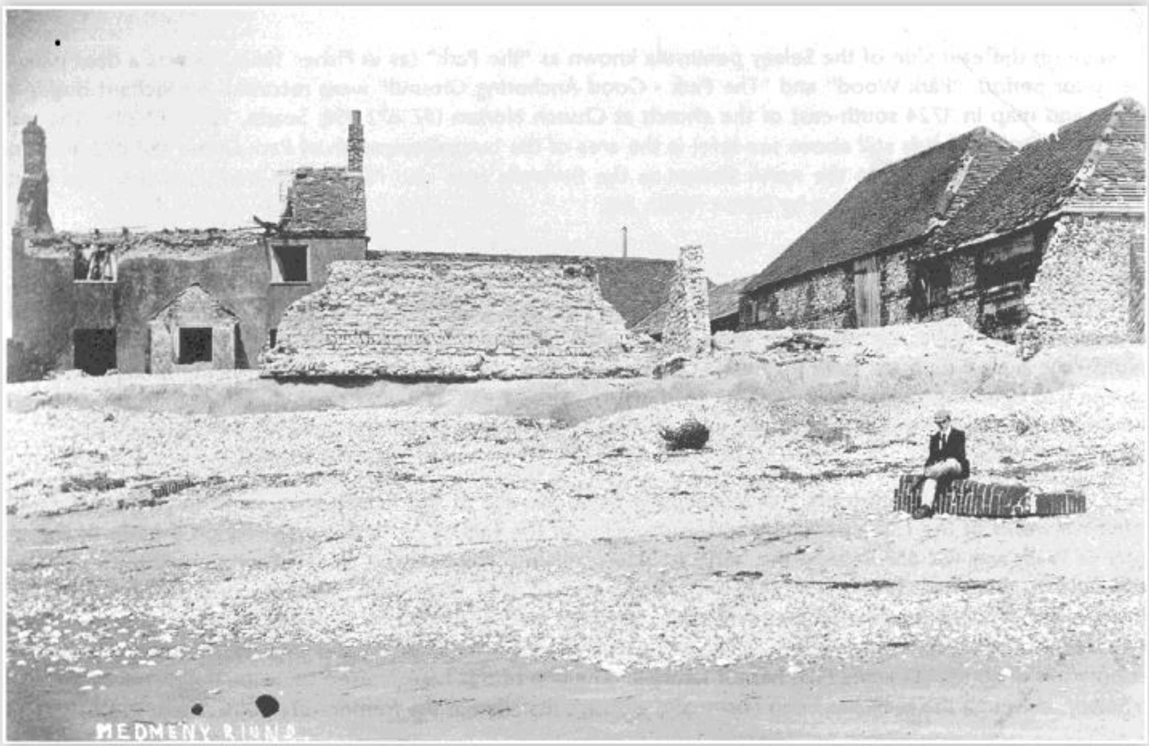

Figure 85 -Postcard showing the effects of erosion undermining the buildings at Medmerry Farm in about 1900 (reproduced in Bone 1996).

The 19th century also saw the end of mining of stone from the Mixon reef, located offshore of Selsey Bill, which exacerbated coastal erosion around Selsey. The mining was stopped by order of the Admiralty, as it was affecting the integrity of the anchorage to the east. The late 19th century saw a spectacular period of erosion in which 18m of land on the west side of Selsey Bill was lost to the sea between 1889 and 1891, including the land up to Medmerry Farm, which was undermined by the erosion (Figure 85). By the 21st century further erosion to the west side of Selsey Bill was threatening the property and livelihoods of the residents of Selsey and in particular the leisure industry and large seasonal populations of the caravan parks on the west side of Selsey Bill. As a result the Environment Agency took the decision to create an area of Managed Realignment at Medmerry, in effect by returning the low lying land to an area of coastal marsh. The scheme, the biggest to date within Britain, was intended to reduce the impact of coastal erosion whilst also providing an area of coastal wetland for wildfowl. The works were carried out by the Environment Agency, with ownership of the area passed over to the RSPB once the scheme had been completed.

The archaeological works in advance of the Medmerry Managed Realignment Scheme identified a number of linear wattle-built structures built to exploit the earlier landscape of Selsey Bill. These structures are important in helping to unpick the complex development of the landscape around Selsey Bill, their function, the context in which they were placed and the information contained in the form of their constituent components can help to explain how the land was being exploited and so what the nature of the landscape may have been. A detailed recording of such structures therefore tells us not only where they sat within their contemporary tidal frame, but how they were constructed and adds to our understanding of landscape practices in intertidal and coastal wetlands.

7.2 Terrestrial Laser Scanning and Terrestrial Excavation

Archaeological recording at Medmerry focussed on the areas most affected by the realignment scheme namely the deep 'borrow pits' excavated to extract clay for construction of the bund, to retain water and provide a habitat for waterfowl. The low-lying nature of the site and the presence of marine alluvial deposits sealing in the archaeology meant that there was a high potential for the survival of well-preserved waterlogged archaeological artefacts and palaeoenvironmental evidence within these areas, and a need to record and recover such material before it was destroyed by the creation of the borrow pits. In particular, an assessment of the area within Borrow Pit 8 (BP8) revealed a long linear wooden structure, running for over 120m in an area of former coastal wetland. An initial radiocarbon date from the structure gave a date of late 14th to early 15th centuries AD. Further archaeological investigation was delayed by the winter weather which covered the site with 1-1.5m of water, and the excavation was eventually carried out in July and August 2013. As the structure was over 120m long the decision was made to excavate a representative sample of 20% by placing fifteen 2mx2m slot trenches at regular intervals along its length. The excavated structure comprised upright posts, predominantly of oak (*Quercus sp.*), which had been sharpened and driven into the ground at intervals of around 0.5m with courses of wattle woven in between them to form a long fence-like structure. The material used for the wattle was identified as willow (*Salix sp.*) or poplar (*Populus sp.*), the ambiguity existing as there are difficulties in identifying the difference between the two at a microscopic level. The wattle built structure extended outside of the area covered by Borrow Pit 8, leaving its total length unknown, but being greater than 120m.

Figure 86 - Example of the linear wattle built structure uncovered during excavations in advance of the Medmerry Realignment Scheme in 2013. The substrate in which the structure was located (grey/blue) has been overlain by later sediments (sand/brown) as the landscape drained.

The TLS survey was carried out using a Leica C10 ScanStation, a time-of-flight terrestrial laser scanner capable of a maximum range of *c.*200m. Each individual trench along the wattle-built structure was recorded using 3-4 setups in order to minimise 'shadows' or voids within the data (See Section 3.6.2 above). The average spacing of measurement on the structure was ≤2mm. The individual scans were registered together using common targets, enabling an overall registration accuracy of the point cloud to *c.*5mm. The registered dataset was then geo-rectified using co-ordinates provided by GNSS control, leading to an overall survey accuracy of ≤13mm.

Equipment Used	Positional Accuracy
Leica ScanStation C10 TLS	±6mm
Topcon GR-3 GNSS	±15mm
Registration Error	±4mm
Cumulative Uncertainty	**±25mm**

Table 14 - Cumulative uncertainty in the survey at Selsey Bill

The TLS survey involved two separate phases of fieldwork, one to record the initial excavation of the structure (Trenches 1-6), with a second visit to record the extension of the excavation to the south of BP8 (Trenches 7-10), and the earlier phase of wattle-built structure located in Trench 2. The initial survey took place on the 1st and 2nd of July 2013 and involved the recording of Trenches 1-5 at the level of excavation achieved by this date. Trench 6, which had been scheduled for survey, was inaccessible due to the proximity of nesting ringed plover (*Charadrius hiaticula*), an unforeseen hindrance to the archaeological works. In total the initial survey involved 19 separate station setups with an estimated 102,058,342 measured points collected. A follow-up survey took place on the 12th August 2013 and involved the recording of Trenches 7-10 which had been fully excavated and cleaned. An extension to Trench 2, which had uncovered an earlier line of wattle-built structure, was also recorded. In total the second phase of fieldwork involved 14 separate station setups, gathering an estimated 73,480,490 measured points.

Figure 87 – Terrestrial laser scanning of trench 2 of the linear wattle-built structure at Medmerry

In parallel to the terrestrial laser scanning survey the structure was recorded using traditional archaeological methods. As mentioned above (Section 2.9), waterlogged wooden artefacts are extremely important both as 'ecofacts' and as descriptors of the technology used to create them. As ecofacts waterlogged wooden artefacts can provide information of woodland ecology; landscape management such as species selection, coppicing and pollarding as well as timber working technology. The organic nature of the material also provides the ability to date deposits, not only through the use of radiocarbon dating, but through dendrochronology, allowing the dating of individual timbers down to the year or even the season of their felling. Along with providing site-specific dating, the collection of dendrochronological sequences can also help to improve the resolution of regional chronologies leading to more exact dating of material. The recording of waterlogged wooden material therefore involves a considered and structured approach in order to maximise the value of the information gathered. The increasing interest in wetland archaeology grew from work carried out in the 1970s and 1980s, from projects such as the Fenland Survey and excavations in the Somerset Levels (See Section 2.5 above). The formation of the Wetland Archaeology Research Project in the late 1980s led to the publication of guidelines in the recording, analysis and conservation of waterlogged wood from wetland archaeology sites (Coles 1990). The standard procedures for recording wetland archaeology, and in particular waterlogged wood, developed during this period have not greatly changed and remain largely intact in current guidelines (English Heritage 2010). These guidelines informed the standard archaeological recording at Medmerry and included the hand survey of plans at a scale of 1:20, with sections and elevations of the structures drawn at 1:10.

Figure 88 – Example of the onsite drawings by ASE. The plan shows the linear wattle built structure in Trench 2 drawn at 1:10 (each large square represents 0.5m).

Each individual component was numbered so that its original location could be easily identified once it had been lifted. In both cases survey control was provided by Archaeology South-East through the use of GNSS. GNSS was also used at a landscape level to map the line of the structure and other similar structures elsewhere on the site.

7.3 Comparison of recording techniques

Wetland archaeology is seen as a distinct sub-discipline within archaeology both in terms of fieldwork and theoretical approaches. This distinction exists for several reasons. Firstly, the archaeological evidence is radically different to that recovered from dryland sites, not only because of the higher levels of preservation noted above (Section 2.9) but also because the occupation and exploitation of wetlands requires differing technologies and practices. Secondly, there is a much greater likelihood of the survival of evidence which would be lost in dryland contexts. These are largely organic in nature, comprising both anthropogenic artefacts such as waterlogged wood and fibres, as well as palaeoenvironmental evidence such as plant and insect remains. Although these can also be found on terrestrial sites, they are frequently in much greater abundance in wetland sites. Finally, wetland archaeology can be seen as a sub-discipline due to the requirement for a different set of archaeological skills. Wetland archaeology sites that have survived have done so because of their existence within waterlogged areas, and this presents unique technical challenges in the excavation, recording and preservation of material. The presence of delicate organic material requires a more sensitive approach to terrestrial archaeology and a level of precision that makes it highly time consuming. The greater survival of organic materials also means that there is a need for a greater understanding of palaeoenvironmental practices and geoarchaeological approach, with much more emphasis on sampling of deposits for further analysis.

The recording of structures such as those found at Medmerry therefore involves detailed drawings of plans, sections and elevations, along with analysis of the wood from a cultural (tool technology and woodmanship) and ecological (environmental reconstruction) standpoint. Significant elements of such structures are frequently preserved for further recording or analysis off-site. However, the delicate nature of the artefacts can inhibit this process, and the methods used for storage can, even in the short term, be seen to impact on their integrity (Lobb *et al.* 2010). In addition, excavation of waterlogged features by its nature alters the water table surrounding waterlogged organics, a process that is further accentuated by the scheduling of most excavations on waterlogged deposits in the summer months, when water provides less of a logistical issue. Recording of waterlogged features is therefore carried out a quickly as possible, but the length of time required to record complex structures at a high level can cause further drying out and deterioration of the wood. Minimising the amount of time spent recording whilst maximising the quantity and quality of data collected is therefore of the utmost importance. Wetland archaeology sites have the ability to provide a wealth of material evidence unobtainable from other comparative contexts. However, the extremely challenging nature of the sites, and the delicate nature of the archaeology means that a lot of time is required to excavate, record and extract material. In addition, a higher level of post-excavation assessment of material is required, with a greater need for conservation of organic materials, a larger palaeoenvironmental resource to be assessed by specialists, and an increased requirement for long-term curation of the resource. In particular, recording on site is highly time-consuming, with the organic nature of the material meaning that structures and artefacts are complex in geometry and structure.

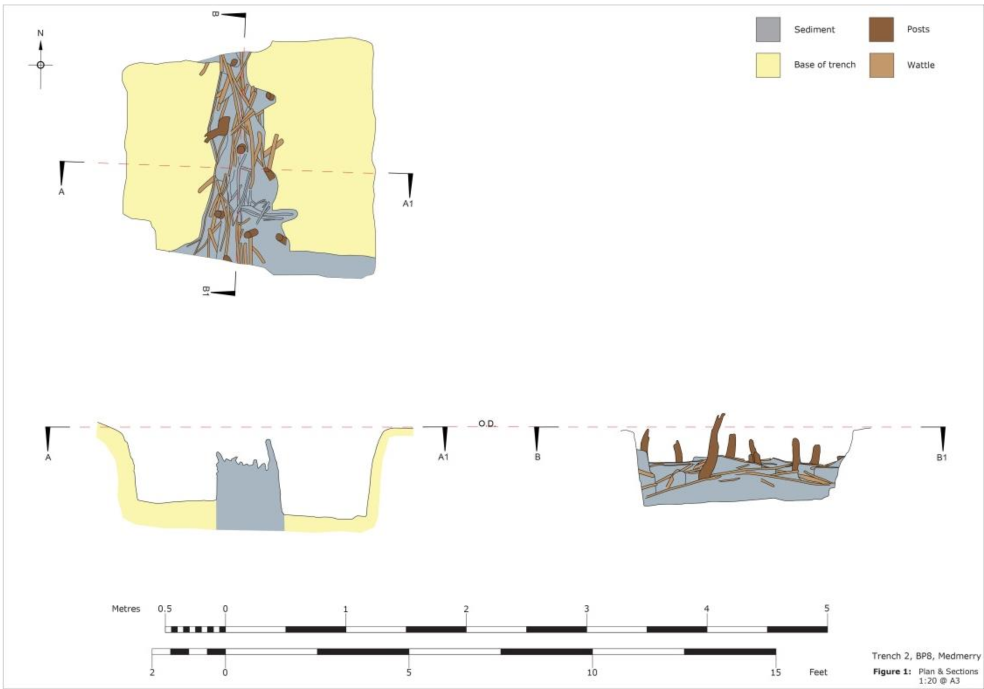

Figure 89 - Plan and sections of the linear wattle-built structure at Medmerry derived from terrestrial laser scanning data using AutoCAD software.

By comparison, the use of terrestrial laser scanning in such scenarios can be seen to greatly increase the speed at which structures can be recorded. A comparison of the recording techniques used at Medmerry shows a radical difference in the amount of time required for each. Using terrestrial laser scanning, each of the trenches could be scanned by one person within the period of an hour, meaning that several trenches could be recorded using terrestrial laser scanning within a working day. By comparison, hand recording of each of the trenches in the form of plans, sections and elevations took two people approximately one day. Terrestrial laser scanning does not automatically produce line drawings equivalent to those produced through hand recording, but rather provides a dataset from which such drawings can be produced at a later stage. However, the question can be raised as to whether producing such drawings is always necessary or whether it is done by rote. Terrestrial laser scanning provides the option of producing drawings if and when they are required rather than automatically recording information that may be of little or no use.

The optimisation of time on site minimises the amount of time that the structure is exposed and so makes it less likely that the material will dry out. This has the advantage of preserving the integrity of the evidence and increases the possibility of lifting and retaining the material. Furthermore, the reduction of man hours means that more resources can be devoted to the excavation of the structure and thus more information can be gathered. Recording through the use of terrestrial laser scanning is in effect scale-less, meaning that the structure can be viewed in detail at the required 1:10 scale (whilst also providing more detail than traditional 1:10 scale drawings), but also provides the ability to record all the features at a landscape level, each feature being placed automatically within the same database rather than being recorded as one of a series of disjointed drawings. Comparison of relative heights across the site and even the landscape is therefore easily achievable.

Figure 90 - Screenshot from the flythrough animation of the terrestrial laser scanning survey of the linear wattle built structure at Medmerry

Finally, terrestrial laser scanning records the structure in three-dimensions not two-dimensions. Wattle-built structures are tremendously complex and reducing them to a flat two-dimensional drawing removes a high level of detail and understanding. Traditional outputs such as 1:10 and

1:20 scale drawings can still be produced from the point cloud through the use of CAD based software, but the ability to view and understand in three-dimensions is a greatly underappreciated resource, representative visualisation of archaeological artefacts, sites and structures is not merely a glitzy tool but a very real and effective interpretive aid.

A fly-through animation of the point cloud was created to show the position and contents of each trench within the wider context of the archaeological excavation. This short two-minute video helps to not only understand the distribution and orientation of the trenches but also to show the circumstances in which the excavation tool place, in effect forming a 'virtual tour' of the site. This animation has been successfully used in a number of presentations to academic and local interest groups, and was also shown to the Environment Agency as part of the report into the work on site. Feedback from these sessions showed the value of the animation as a means of engaging audiences in the realities of the site to a greater degree than photography or illustration could have done.

The three-dimensional data can also be viewed and interrogated using an .html based viewing platform (Leica Truview) which allows the manipulation of the data as well as allowing basic measurements to be taken and notes or comments attached to features within the point cloud. This means that the data can be viewed in its full three-dimensional form from any location, allowing collaboration on the interpretation of structures.

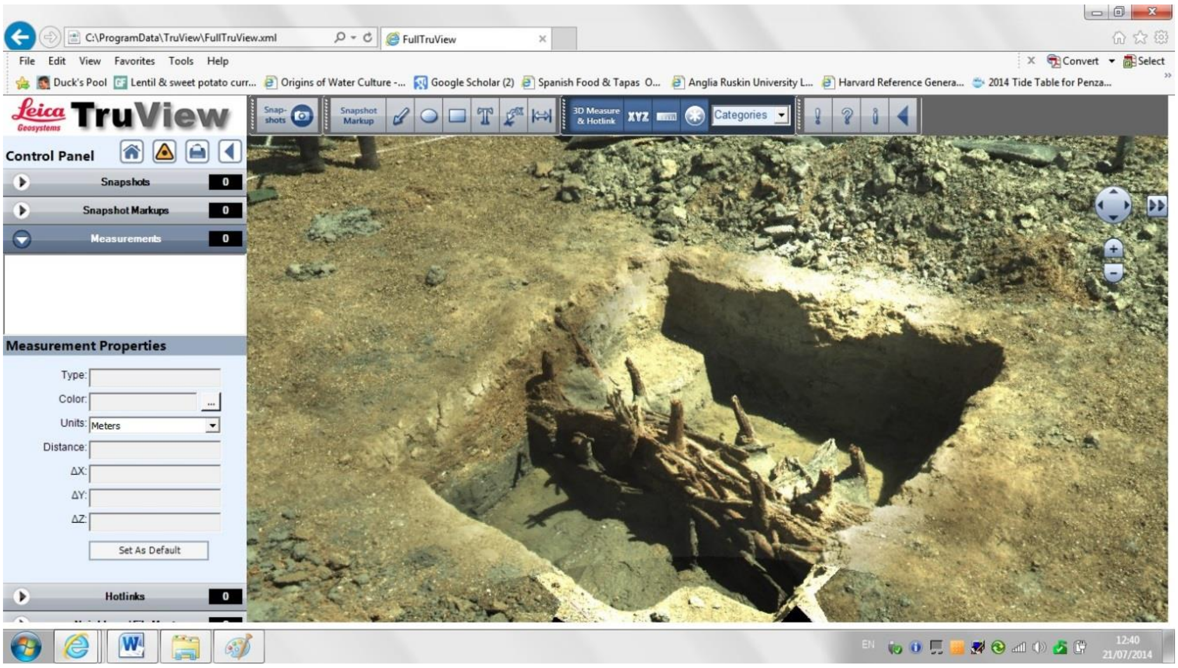

Figure 91 – The terrestrial laser scanning dataset of Trench 2 at Medmerry viewed in Leica Truview software. The main window shows a view of the point cloud while the surrounding menus allow annotation, measurement and manipulation of the data.

7.4 Reconstructing past intertidal environments

Radiocarbon analysis from elements of the linear wattle-built structure provided a range of dates all falling firmly within the 14^{th} century AD. Low-lying coastal wetlands were hugely valued during this period, with a large and concerted effort to drain and convert them to agricultural land, a process commonly referred to as reclamation or land-claim (Allen 1997). The land was of particular value due to its high nutrient content, and could be worth up to one and a half times the value of the surrounding dryland fields. However, an undue focus has been placed on lands reclaimed, with little to no economic importance ascribed to undrained marshland (Gardiner 2007). The decision to leave land undrained rather than to reclaim it can be seen as a conscious economic choice rather than being driven by technological limitation (Rippon 2000). Marshland had an inherent value, containing a wealth of resources such as fish, fowl, salt and peat, whilst also providing good grazing especially for sheep. Most importantly, unlike reclaimed land, marshland did not require investment in maintenance.

The wattle-built structure at Medmerry was located in an area of marshland within a sheltered area of a tidal inlet, which was almost exclusively brackish water. As noted above (Section 2.10) intertidal structures show a remarkable degree of homogeneity, and as a result the structure at Medmerry could have a range of possible functions. A number of industries are recorded in the area during the 14^{th} and 15^{th} centuries AD which could account for the presence of a wattle-built structure. A tidal mill is known at Sidlesham from the 15^{th} century AD, an extensive salt-making industry was present to the west within Chichester Harbour, along with an oyster-fishing industry and evidence exists for a landing place and trade centre somewhere around the Selsey area within this period (Gardiner 2000). Additionally, land reclamation for both pastoral and arable use was extremely popular within the region, a process which is known to have involved the use of wattle fencing to build up the land surface (Cadell 1929).

The most obvious suggestion, however, is that the structure represents a form of fixed fishing, which was widely practised on the Sussex coast at this time (Gardiner 2001), and whilst the structure was clearly not on the open coast, coastal marshland was also used to trap and farm fish. Salzman (1923) recounts that:

> *In 1450 Reynold Manfeld leased at 12d. a year a lagoon called Cotemanware at AppleDram near Chichester in which to set up a kiddle.*

An analysis of the placement of the structure within the tidal frame could potentially help to identify its function. However, there is a confusing relationship between reclaimed or drained marshland and the tidal frame, as the water level in reclaimed land can often be lower than the mean sea level, and in areas containing peat, drying and compaction of sediments can result in shrinkage, leaving a degree of uncertainty about their original height. Comparison with the tidal frame, as seen in Chapter 5 is therefore less productive in such contexts. In interpreting the structure at Medmerry, however, other forms of environmental evidence can be crucial, as the use of the structure would in part be determined by the context of the surrounding wetland. However, the palaeoenvironmental data from around the structure only serves to muddy the waters. Identification and dating of ostracods and foraminifera provides a picture of brackish water, most likely a tidal lagoon or saltpan, irregularly topped up with seawater. However, whilst the dates of the sediment within the lagoon range from the Iron Age and earlier, dating was not possible on the sediments adjacent to the structure. The diatoms suggest that the sediments the structure is driven through indicate accumulation above mean high water spring. In addition, access to the open sea is indicated with the presence of marine diatom species suggesting that coastal barrier breakdown may have occurred before the structure was built (pers. comm. Krawiec 2016). Given the context of the site, it is entirely possible that there has been a large degree of reworking of the sediment around this area, which would explain why a 14th century AD structure is buried in silts with material dating to the post-Roman period. However, a lot more work on the surrounding landscape processes through this period needs to take place to clarify this interpretation. The wood used in the construction of the wattle structure can also be used to shed some light on possible interpretations of the structure. The larger stakes comprised a mix of oak (*Quercus sp.*), willow (*Salix sp.*) or poplar (*Populus sp.*) and fruit tree (*Maloideae sp.*), for the most part left as roundwood or roughly quartered, whilst the weavers were willow (*Salix sp.*) or poplar (*Populus sp.*). It is assumed that the bark was left on, although little remained, and some branches and twigs were still present (Archaeology South-East 2014). The stakes were simply sharpened and driven into the ground. There was no defined consistency in the growth rates suggesting that the material was not the result of managed woodland, but rather that the material was a mix of readily available wood. Compared to the level of investment seen in the structure at le Petit Taureau (see Chapter 5 above), the structure at Medmerry seems a much more ad hoc construction, having been fashioned from readily available materials, simply worked into a functional structure.

The date of the structure puts it within the period of enhanced storminess when we know that other coastal land was being overwhelmed with tidal surges and reverting to marsh. A large number of documentary sources from this period refer to the almost instantaneous construction of fishing weirs on areas of flooded farmland to exploit the change in environment (Galloway 2009). The short lifespan of the structure could suggest an opportunistic exploitation of a changing landscape, which would not have been well represented in the environmental record.

This would help to explain the placement of structure as well as the simplistic nature of its construction.

7.5 Recording intertidal structures in coastal wetlands

Low-lying coastal areas are at risk from both a rise in relative sea level and from periods of enhanced storminess. This is not a new threat along the Sussex coast, as the period of increased storm magnitude from the 13th – 15th centuries AD illustrates. However, the decision to allow managed realignment to occur adds an additional pressure on land that has a long history of significant erosion and flooding. In particular, managed realignment places increased pressure on the archaeological resource, including monuments and structures relating to the reclamation of coastal wetlands, which are understudied and not fully understood (Allen 1997). Reclaimed or drained land also has a high potential for archaeological remains of former intertidal structures, which must be understood in terms of their contemporary landscapes, but also in terms of wider landscape processes. The area surrounding Selsey Bill, like a large proportion of the Sussex coast, has a complex history of moving river systems, silting estuaries, and anthropogenic alteration of marshland. Attempting to unpick historic landscape processes in such an area requires a number of approaches including palaeoenvironmental analysis, archaeological excavation and historical research, and a large body of data must be gathered to fully understand the wider patterns. The use of intensive survey can help place structures and features accurately in a landscape context, but knowledge of wider landscape processes (both on the macro- and micro-scale) is necessary to help define their function. Commercial or 'developer-led' archaeology is driven by the need to record to as full an extent as possible the archaeological evidence uncovered by development. The data gathered from such sites does not necessarily form a coherent or complete narrative, but rather adds to the information base that informs regional and national research strategies. The use of terrestrial laser scanning complements this aim as it can be used to record the maximum amount of information in as accurate a way as possible, whilst also serving to reduce the amount of time spent recording on site. In particular, it can be seen to vastly reduce the burden of recording on wetland archaeology sites, enabling more time to be directed to the exposure and recovery of fragile archaeological remains. The terrestrial laser scanning survey of the wattle-built structure at Medmerry has not directly answered all of the questions about the feature or the wider site, but the accuracy of the data enables it to inform and be used in further studies of this complex and dynamic landscape.

Chapter 8: Monitoring the Effects of Erosion on a Coastal Archaeology Site: Low Hauxley, Northumberland

The following chapter presents a case study of the use of terrestrial laser scanning to monitor coastal heritage at risk. The site at Low Hauxley, Northumberland, is of a different nature than

Figure 92 - Map of Low Hauxley, Northumberland showing the location of the excavation site

the previous case studies, being a terrestrial prehistoric site at risk within the coastal zone from erosional processes; however, it has been included as a case study of the application of terrestrial laser scanning to the study of the effects of coastal retreat on the archaeological resource. Cliff-top and intertidal archaeology sites are increasingly at risk of erosion due to rising relative sea levels and increased storminess (Murphy *et al.* 2009), and it has been argued that this rate is likely to radically increase within the next century under anthropogenic climate forcing (Ranasinghe and Stive 2009). Developing a method of recording and monitoring heritage at risk that can be applied to a wide range of coastal and intertidal contexts is therefore of a very high priority.

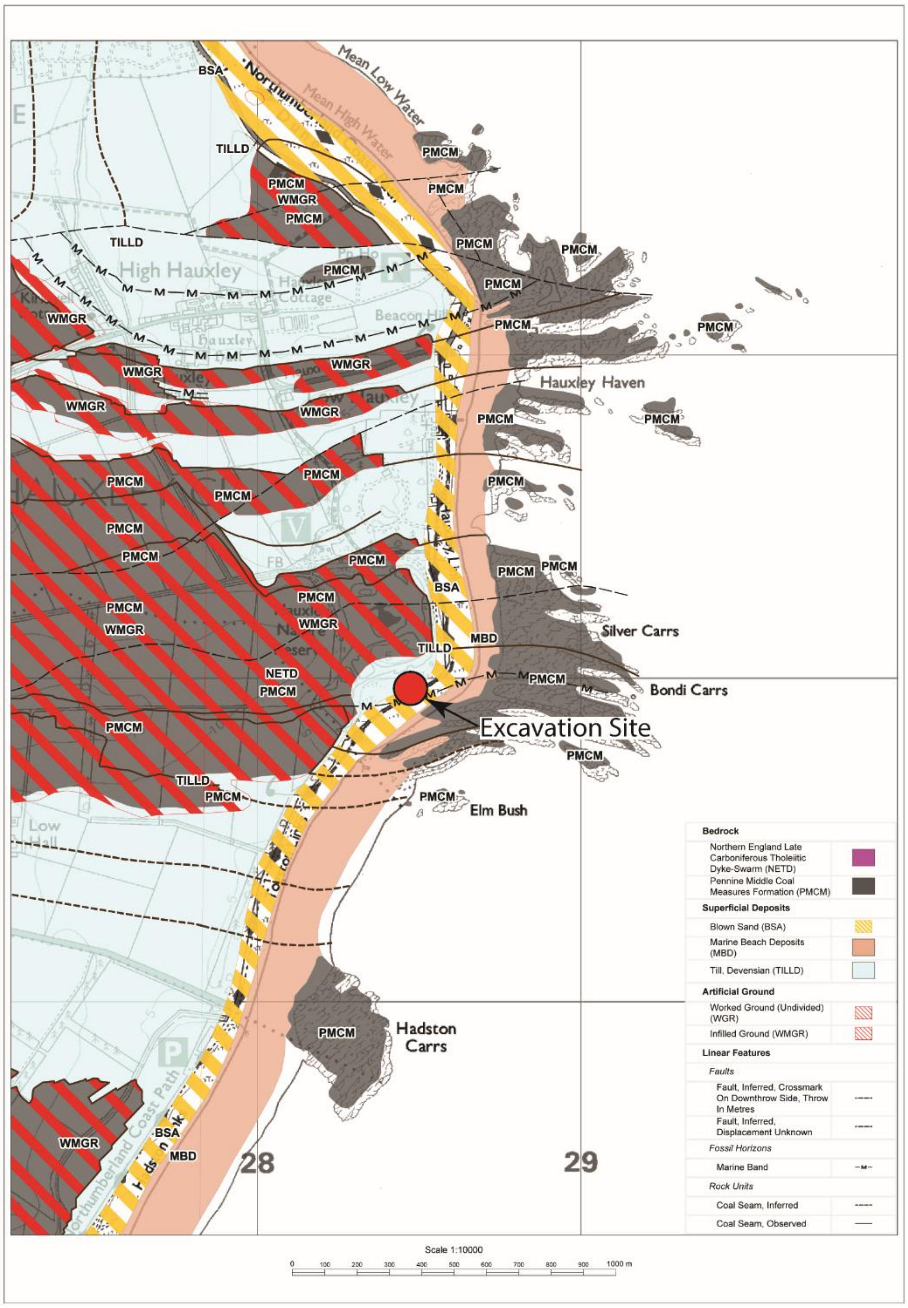

Figure 93 - Map of Low Hauxley, Northumberland showing the underlying geology.

The archaeological site at Low Hauxley is overlain by a coastal dune system, which has served to obscure the extent of the archaeological and palaeoenvironmental deposits. Sites such as Mothecombe in Devon, Skara Brae in Orkney, the Links of Noltland in Westray and Brean Down in Cornwall (Bell and Heritage 1990) have shown the potential for coastal dune systems to contain valuable heritage assets from a wide range of time periods and types. These sites also demonstrate the increased risk of a loss of heritage assets from such contexts, as it is only when the overlying deposits begin to actively erode that the archaeology is revealed, requiring an immediate and thorough intervention. Terrestrial laser scanning can not only be used as a method of recording the archaeology in high detail, but can be used to estimate the rate at which the archaeological deposits and their immediate landscape are being lost to erosion.

The coastal archaeology site at Low Hauxley is located at the north end of Druridge Bay, Northumberland (NGR NU 285 018) approximately 1.2km south along the coast from the modern settlement of the same name. The site comprises a series of Bronze Age burials overlying a Mesolithic land surface with associated palaeoenvironmental deposits, and is buried beneath a narrow strip of aeolian dunes and underlain by Devensian till. The excavation site is located on a locally uplifted knoll of solid geology set immediately above a wave-cut rock platform known as Bondi Carrs. Directly to the west of the site is the Hauxley Nature Reserve, a wetland area reinstated from the land used for open cast mining of the Pennine Middle Coal Measures, which comprise Late Carboniferous (Pennsylvanian) interbedded siltstones, coal and sandstones (Figure 93).

The dune system overlying the site is eroding due to coastal squeeze between the advancing shoreline and the bird reserve to the west, with the short foreshore and hard clay cliffs underlying the dunes leaving little opportunity for dune formation (Guthrie *et al.* 2009). It has also been speculated that subsidence linked to extensive mining in the past, the shafts from which extend out beneath the sea, may be in some part responsible for this erosion (Guthrie *et al.* 2009) although there is no quantitative estimate of this.

Concern over the erosion of the coastline at Low Hauxley is shared by a range of policy bodies; the Environment Agency's Shoreline Management Plan for the area raises concern over the threat to the modern settlement of Low Hauxley posed by the destruction of the dune system. The proposed approach for long-term management of this portion of coast is 'Managed Realignment', defined in SMP2 as "allowing the shoreline to realign, landwards or seawards, sometimes with management to initiate and control change" (Guthrie *et al.* 2009, p*ii*). The area surrounding the site was designated as a Site of Special Scientific Interest (SSSI). The full description states:

> *Low Hauxley Shore is important for Quaternary studies. The interest comprises an extensive layer of woody peat resting on Late Devensian glacial till and overlain by blown sand containing buried soil horizons. These deposits provide evidence for environmental conditions and changes on the coast of NE*

> *England during the last 5000 years. In particular, they indicate retreat of the coastline and different episodes of sand dune development.*

This designation reflects the high potential of the site for the detailed reconstruction of a long sequence of palaeoenvironmental deposits (Drury 1995), and for this reason the Low Hauxley Shore has also been included within the Geological Conservation Review of Northern England. Ironically the threat to the site from coastal change is what in part makes it a valuable resource for palaeoenvironmental studies, as the gradual erosion allows the clear exposure of the deposits for study (Speakman *et al.* 2013). As the site lies directly to the east of the Hauxley Nature Reserve, it also sits within the boundaries of a designated Special Protection Area (SPA) and Ramsar site. The various designations that cover the area surrounding the site reflect the range of stewardships of the coastal area at this location, Northumberland County Council owns the dune system, Hauxley Reserve is owned by the Northumberland Wildlife Trust whilst the foreshore is owned by the Crown Estates. Any effect on the dunes, therefore, be it erosion or through archaeological intervention impacts on a range of different landowning bodies, each with their own vested interest in the condition of the dune system.

Figure 94 - Buried palaeoenvironmental deposits capped by a dune system at the Low Hauxley Shore SSSI. Note the preserved oak tree trunk protruding from the section at the left of the photograph.

Known and predicted rates of erosion at Low Hauxley Shore have been specified in the Shoreline Management Plan. The baseline erosion rates have been estimated at 0.4m per year, with the long-term potential erosion given as 85m over the next 100 years (Guthrie *et al.* 2009). In effect, this would mean that within the next century the entire area currently covered by the dunes will have been destroyed by the advancing coastline.

8.1 A History of Archaeological Monitoring at Low Hauxley

Archaeological investigation of the site at Low Hauxley began in 1982 in response to a report by a local amateur archaeologist of burial cists eroding from the cliffs (Drury 1995). The following year an investigation, consisting of field reconnaissance and rescue excavation was carried out by the University of Edinburgh led by Clive Bonsall. This revealed a large Bronze Age cairn containing human remains dating to 2140-1890 cal BC with a smaller satellite cairn containing human remains dating to 1880-1640 cal BC (Drury 1995). Both contained flexed inhumations, with the main cairn also having a cremation inserted near to the cist. The buried land surface beneath the cairns contained a small quantity of midden material of Mesolithic date (approximately 5000 BC) comprising shells, a single fish bone, mammal bones and plant material (Bonsall 1984). A further phase of work occurred in 1992-3, after two further stone cists were

Figure 95 – Photograph of Cist 1 protruding from the cliff section at Low Hauxley, recorded during the 1993 excavation. Scales: 1m. (Speak and Griffiths 1993).

exposed by the winter storms (Figure 95). The excavation, led by Tyne and Wear Museum Service, revealed two cists dating to the Bronze Age. Cist 1 contained a bell beaker and cremation, whilst Cist 2 contained a bell beaker and an inhumation which was later identified as that of a young man, 12-15 years old (Brayne 2002; see Waddington and Bonsall (forthcoming) for a detailed account). A further cremation was found outside the cists. As the excavation was unfunded little to no environmental analysis of the site was carried out (Speak and Griffiths 1993).

The obvious importance of the site, to both archaeological and palaeoenvironmental studies prompted a larger programme of investigation and excavation in 1994 led by Lancaster University Archaeology Unit and funded by English Heritage (Drury 1995). The project involved placing two trenches to the rear of the dunes to recover more palaeoenvironmental evidence from the buried Mesolithic land surface, and survey of the cliff face in plan and section. Erosion over the winter of 1994-5 revealed further burial slabs, believed to be part of a cist, eroding from cliff 34m to the north on Cairn 1 (Drury 1995).

The site at Low Hauxley was included within the area covered by the North Eastern Rapid Coastal Zone Assessment (RCZA). Both Phase 1, a rapid desk-based assessment, and Phase 2, a fieldwork assessment, were carried out by Archaeological Research Services Ltd (ARS Ltd) between 2007 and 2010 and highlighted the high importance of the site and the high risk of erosion. During this period a further cist burial and pit burial below the large cairn containing a beaker were reported as eroding from cliff and recorded by ARS (Waddington and Cockburn 2009). In 2010 an area of intertidal peat containing animal and human footprints, located to the southwest of the main site, was also recorded after being exposed by the winter weather (Waddington and Bonsall (forthcoming)).

Investigations prior to 2013 at the site of Low Hauxley have constituted a reactive rather than proactive response to the recording of threatened coastal archaeology. Despite a continual call for the further investigation of the site, the time elapsed form the first identification of the archaeological site through erosion to the full excavation of the cairn and associated deposits was exactly 30 years. During this time the rate of erosion was substantial, witnessed by episodic exposition of significant archaeological features. If the rate of erosion estimated by the current Shoreline Management Plan is taken at face value, over this 30-year period the loss of material containing archaeological and palaeoenvironmental deposits at Low Hauxley Shore could have been anything up to 12m.

The majority of archaeological investigation at Low Hauxley prior to 2013 has been in the form of ‘rescue excavation’ and as such has mostly been recorded using standard archaeological planning utilising hand survey, with total stations used to provide location. Earlier excavations on the site by Bonsall in 1983, and those by Tyne and Wear Museums in 1993, do not appear to have featured measured survey. However, the evaluation trenches and borehole survey by the then Lancaster University Archaeology Unit in 1994 established on-site control points using differential GPS, which were also used to map the line of the adjacent cliff at both base and top.

A total station was then used to record the top and bottom of the cliff face along with the base of the peat in section. This survey was carried out with the intention of providing an accurate baseline survey for future monitoring of coastal erosion at the site (Drury 1995). Unfortunately, this monitoring never took place, and the report was never fully published. The current location and nature of the digital archive, including CAD plans, is unknown.

8.2 Aims of Terrestrial Laser Scanning survey

The terrestrial laser scanning survey at Low Hauxley took place as part of the 2013 'Rescued from the Sea' project led by Archaeological Research Services (See Waddington and Bonsall (forthcoming)). The project aimed to fully excavate the Bronze Age cairn in response to the threat posed by coastal erosion. The excavation involved the use of more traditional methods of archaeological recording in the form of hand survey and photography, as well as the use of a total station to map significant features and finds. The inclusion of terrestrial laser scanning as a method of recording the site was intended to satisfy three specific aims:

1. To record in a high degree of detail the Bronze Age burial cairn and buried land surfaces/palaeoenvironmental deposits
2. To quantify the overburden overlying the archaeological deposits
3. To assess the reinstatement of the dune system after the excavation had concluded

The extreme weather over the winter of 2013/14 led to the addition of a further aim:

4. To provide data on the rate of erosion and cliff recession at the immediate area surrounding the site

This chapter will primarily deal with the aim 4, the effects of the 2013/14 winter storms on the dune system, and in particular on the underlying archaeological and palaeoenvironmental deposits. The need for long-term monitoring of sites coupled with the rapid advance in metric survey technology has often led to more than one technique being used monitor a site. Chapman *et al.* (2001) compared contemporary global navigation satellite system (GNSS) mapping of the shoreline to historic aerial photography and archaeological survey in GIS in order to monitor coastal change over a period of 53 years. The effects of erosion on intertidal peats at Westward Ho! in Devon was likewise measured in GIS using comparisons between aerial photography and GNSS survey carried out 18 years apart (Riley 2002). Similar approaches have been used to monitor rates of erosion/accretion on coastal dune systems, using comparisons between GNSS, total station, airborne laser scanning (ALS), aerial photography and historic mapping to attempt to construct as long a sequence of coastal change as possible (Kandrot 2012). Whilst these approaches are valuable in their ability to look at a much longer pattern of coastal change, the extent of erosion can only be measured in plan form, and calculated by area. Furthermore, the use of mixed technologies, each with varying degrees of accuracy, leads to an increasing level of inaccuracy in comparing surveys, meaning whilst a general trend can be shown, the detail of the processes behind the erosion are much more difficult to detect.

More recently approaches have focused on the use of three-dimensional recording techniques to analyse coastal erosion. Both ground-based and aerial photogrammetry along with ALS and TLS have been applied to the monitoring of coastal change, with the accuracy of ALS having been shown to be much greater than that of photogrammetry (Adams and Chandler 2002). Likewise, within ground-based survey, terrestrial laser scanning has proven to be a preferable approach due to the inherent problems in calibrating photogrammetric imagery of steep cliff faces (Lim *et al.* 2005). Olsen *et al.* (2009) have trialled the use of kinetic TLS to survey large areas of coastline, covering an area of 17km with a high degree of accuracy.

The challenge in recording the site at Low Hauxley was to balance the need for wider topographic survey of both flat and vertical topography and detailed recording of the archaeological and palaeoenvironmental deposits. In this context other approaches such as photogrammetry or GNSS/Total Station survey would have required a mixed technological approach. TLS was ideally suited to the variance in range and resolution required on site whilst maintaining a high degree of accuracy in the collected data. TLS was applied to the site as a whole and to the eroding cliff sections.

The survey involved detailed recording of the structure of the cairn during excavation, high resolution surveys of the palaeoenvironmental deposits both at the site itself and on sections of cliff 200m to the north, as well as a section of peat in the intertidal zone to the southwest of the main site. The resulting data meant that a full record was made of the dunes overlying the site at a resolution of ≤10 mm prior to, during and after the winter storms of 2013-2014. The high resolution of the dataset means that volumetric changes to the area as a whole could be calculated, but also that changes to individual deposits within the structure of the cliffs could be detected.

8.3 Methodology

The survey of the site was carried out using a Leica ScanStation C10 scanner. Reference targets were placed over established stations on the site grid, or offset from the site grid using a total station. This meant that data gathered on site could be immediately georeferenced, with the permanent ground control enabling a high level of control between surveys. The use of permanent ground control is especially important at any site where long term monitoring is taking place, as it significantly reduces the margin of error between datasets, allowing as detailed as possible a comparison to be made. In each of the surveys the topography of the site was recorded to an average point spacing of *c.*4 mm, with significant archaeological and palaeoenvironmental features recorded at a higher level of detail (*c.* 2mm point spacing). Each survey was closed with a cumulative RMS error of less than ±10 mm, within the parameters set for metric survey of archaeological features (Bryan *et al.* 2009). This was well within the limits of the proposed methodology outlined above (see Section 3.6).

Figure 96 – Results of the terrestrial laser scanning survey of the site at Low Hauxley (see Chapter 8 below), with RGB colour values taken from the internal camera mapped over the point cloud.

The TLS survey of the site involved several phases of fieldwork, with the aim of recording the site prior to, during, and post-excavation. An initial survey took place in May 2013 to form a baseline record of the site and consisted of a general topographic survey of the beach and overlying dune system surrounding the site. Two visits were made during the course of the excavation. In July 2013 the fully exposed cairn was recorded along with portions of peat bed within the intertidal area to the south of the site. In August 2013 a return visit was made to record the land surface uncovered after the cairn had been removed, along with cleaned up cliff sections revealing the deposits underlying the main excavation site and extending to the north of the site. The site was reinstated in September 2013, and was subsequently badly affected by the winter storms. The final survey was carried out in March 2014, after the winter storms, and involved surveying an identical area as that covered by the initial survey, to record the now reinstated site, as well as recording a small area of excavation to the north of the main site where archaeological remains had been exposed by the winter storms.

Equipment Used	**Positional Accuracy**
Leica ScanStation C10 TLS	±6mm
Leica 800 TPS	±5mm
Registration Error	±7mm
Cumulative Uncertainty	**±18mm**

Table 15 - Cumulative uncertainty in the survey at Low Hauxley

8.4 Results and Interpretation

The data gathered onsite was initially processed in Leica Cyclone software. All datasets were fully registered and georeferenced within Cyclone. Extraneous points were removed from the point cloud and the resultant dataset archived in *.pts* format, an open ASCII file format, in accordance with guidelines provided by English Heritage and the Archaeological Data Service (Mills and Andrews 2011; Payne 2014). The volume of data gathered through the use of TLS is substantially higher than that produced by alternative forms of metric survey, due to the much higher resolution involved. This has obvious implications for long term storage and curation of the dataset. The initial database for all of the survey carried out at Low Hauxley was around 40 gigabytes in size, with the registered, cleaned and exported files for each survey averaging a size of around 6 gigabytes.

8.4.1 Two-Dimensional Cliff sections

The exported data from each of the three surveys was then imported into AutoCAD software and used to produce standard two-dimensional cliff sections. These comprise eight cross-sections spaced 10 m apart running perpendicular to the line of the cliff (Figure 97).

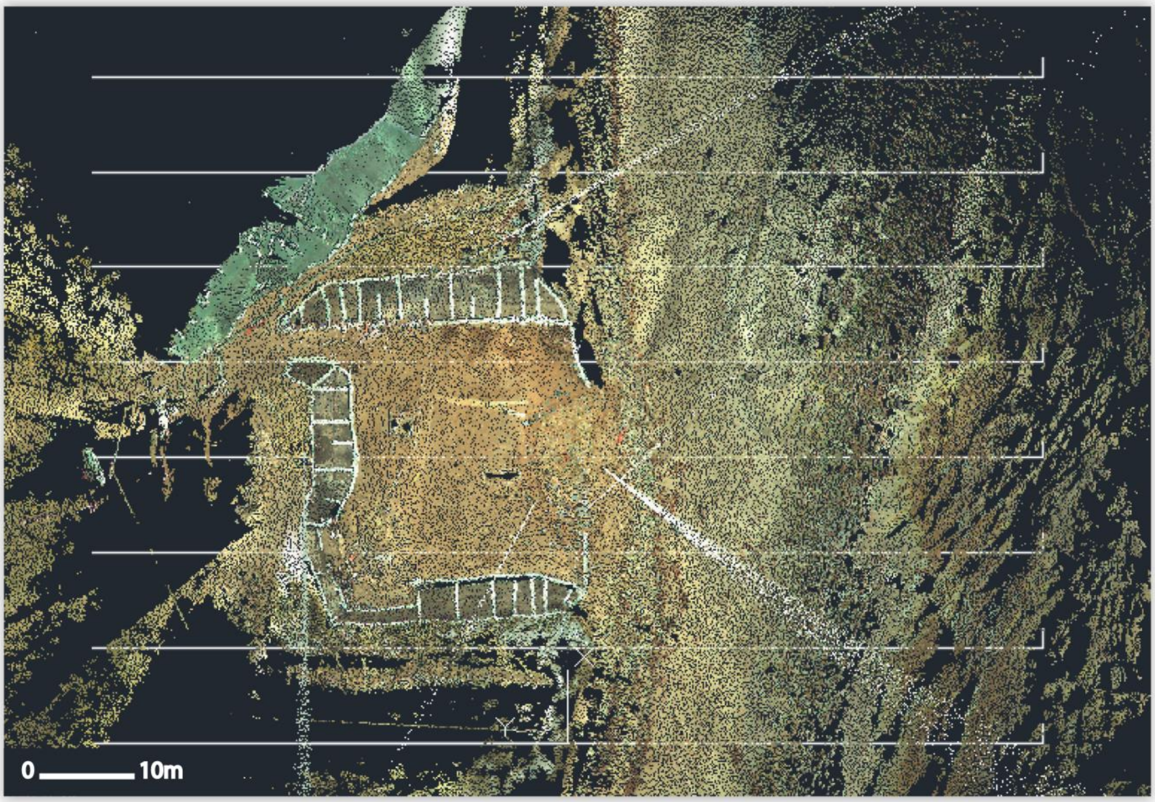

Figure 97 - Plan view of the point cloud of the Low Hauxley terrestrial laser scanning survey viewed in AutoCAD software. The white lines represent the cliff sections used below.

Importing the datasets into AutoCAD enables a 'slice' to be taken through the point cloud at an orientation defined by the user and, as each dataset is georeferenced, an identical slice can be taken through each subsequent dataset along the same transect (Figure 98). These slices can then be used to generate cross-sections, and the cross-sections overlaid for comparison. The advantage of generating the cliff sections using this method, rather than the traditional approach of recording transects in the field using a theodolite or dumpy level, is that the location of the transect does not have to be selected in the field, but rather can be chosen at any point from the dataset. In the case of the site at Low Hauxley this was particularly important as it meant that a cliff section could be drawn directly over the centre of the cairn, the location and alignment of which was not fully known prior to the excavation. This use of TLS data also means that an infinite number of section lines can be created; and, because the resolution is much greater, a much higher level of detail can be extracted from the dataset.

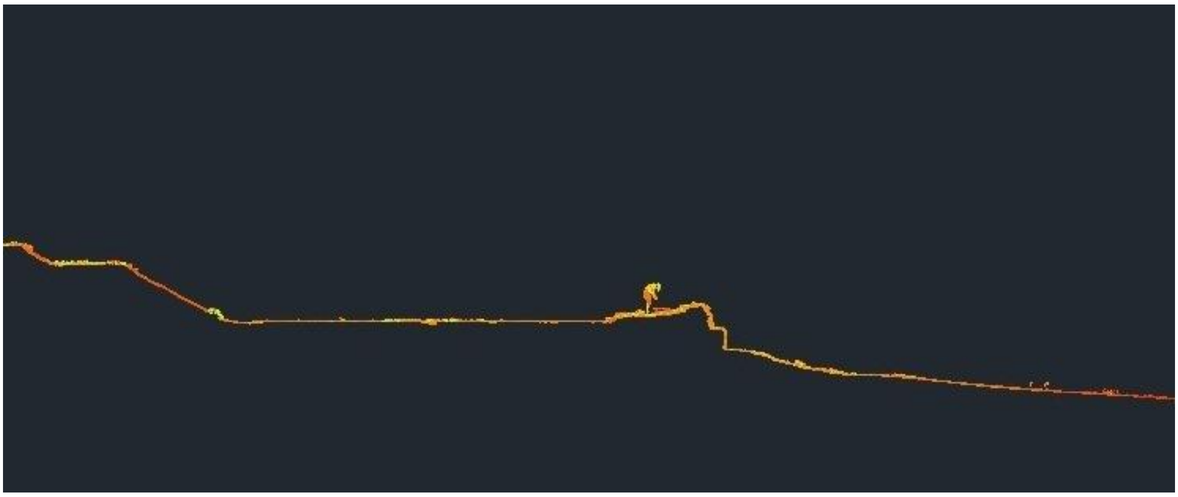

Figure 98 – Northwest-southeast 'slice', generated in AutoCAD software, through the 2013 excavation at Low Hauxley, complete with archaeologist planning the Bronze Age cairn

The cliff sections generated allow the quantification of the impact of the excavation and reinstatement, and show the effects of the winter storms on the various deposits at set transects along the cliffs (See Figures 99-102 below). Measurement between the cliff sections in CAD was further used to establish the varying rates of erosion at different points along the cliff (See Table 16 below).

Section	Maximum rate (m)	Minimum rate (m)	Mean rate (m)	Range (m)
1	1.7273	0.0434	0.74091	1.6839
2	0.3544	0.0127	0.22549	0.3417
3	1.0322	0.1967	0.5491	0.8355
4	1.6025	0.695	1.25027	0.9075
5	0.728	-0.3251	0.27113	1.0531
6	1.1534	0.1877	0.70445	0.9657
7	1.292	-0.3431	0.83542	1.6351
8	1.8217	-0.2885	1.04208	2.1102
Total	1.8217	-0.3431	0.7023563	2.1648

Table 16 - Estimates of cliff face recession from TLS derived cross-sections

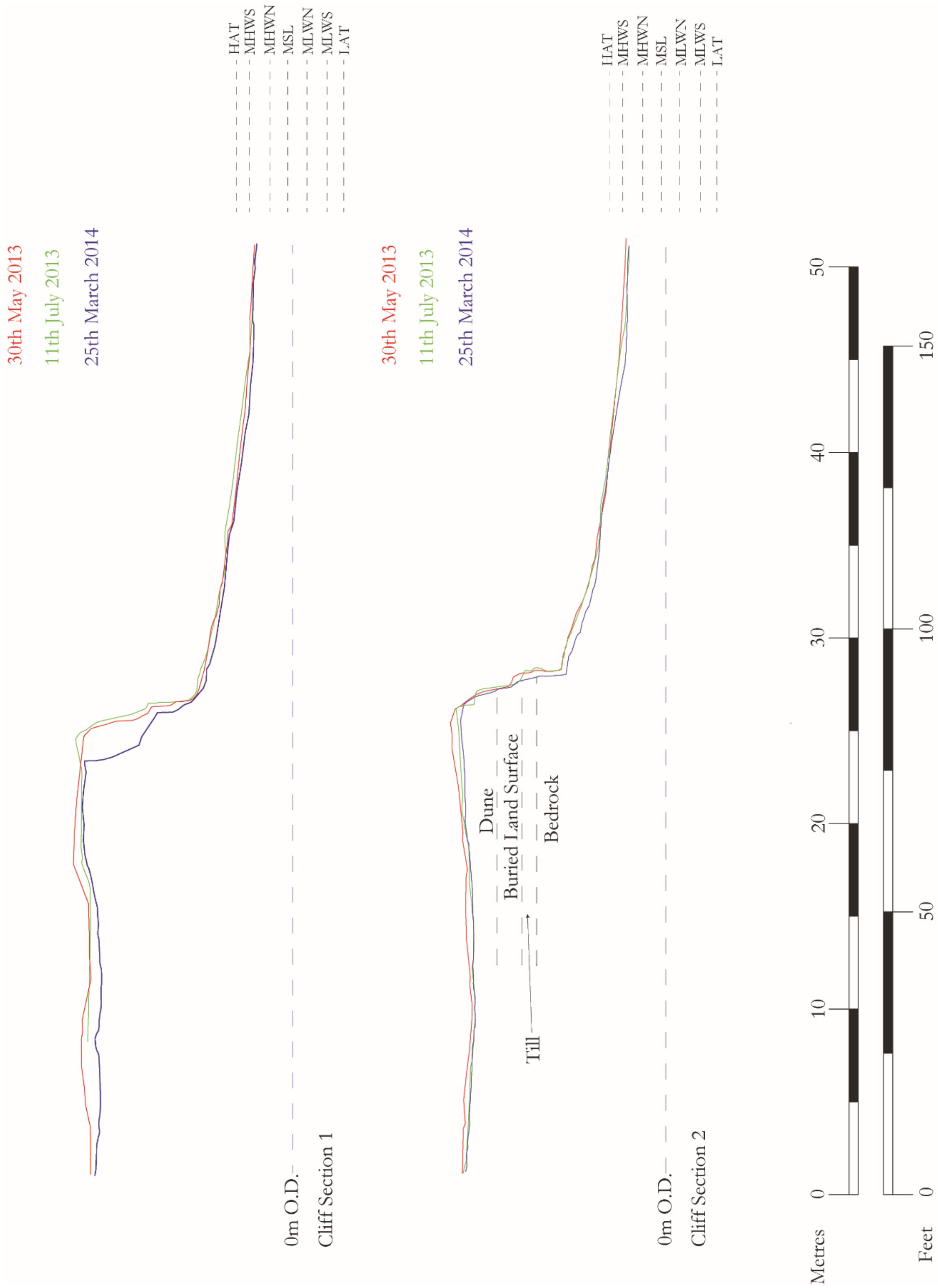

Figure 99 - Comparative cliff sections 1 & 2 (1.5x vertical exaggeration).

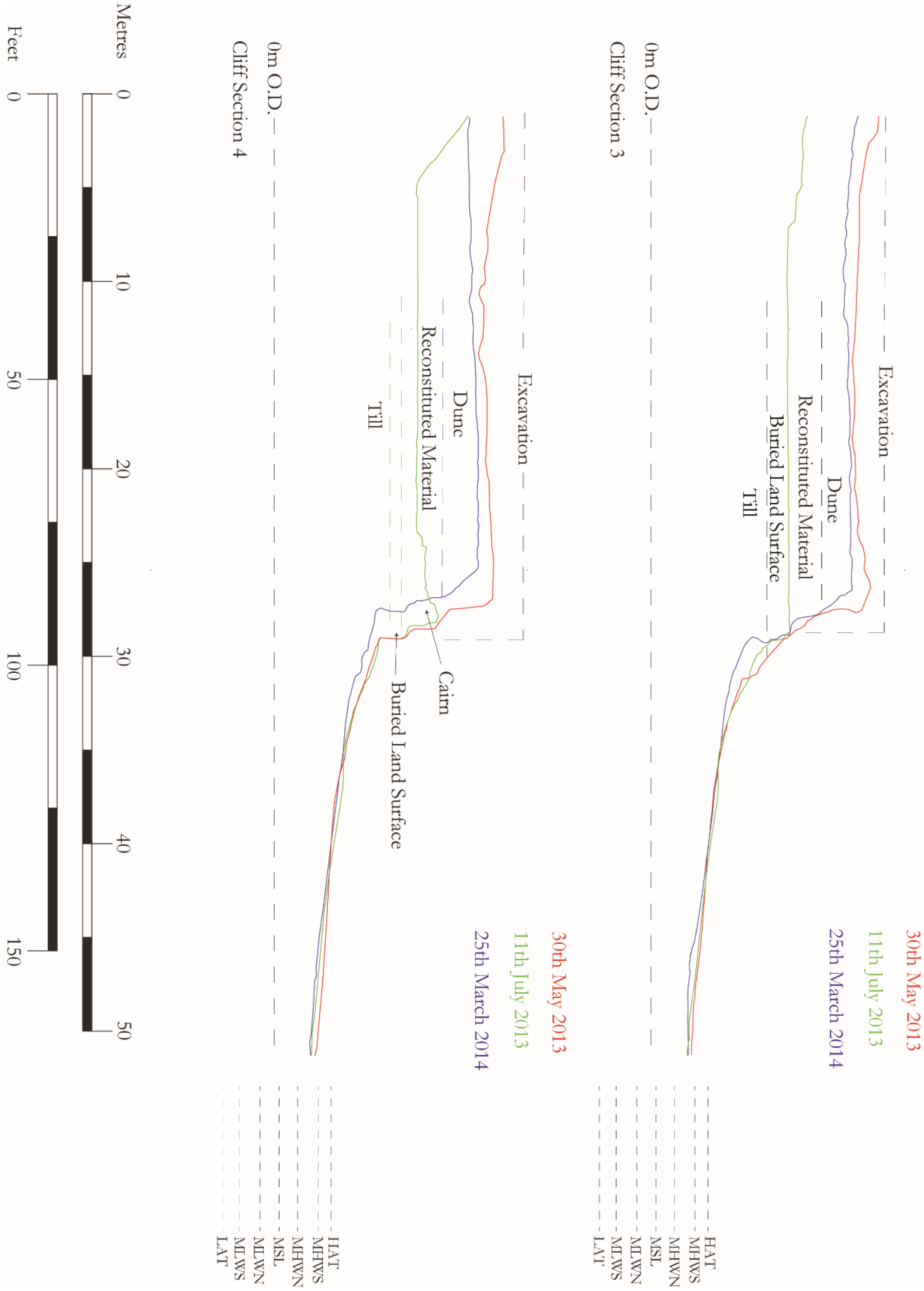

Figure 100 - Comparative cliff sections 3 & 4 (1.5x vertical exaggeration).

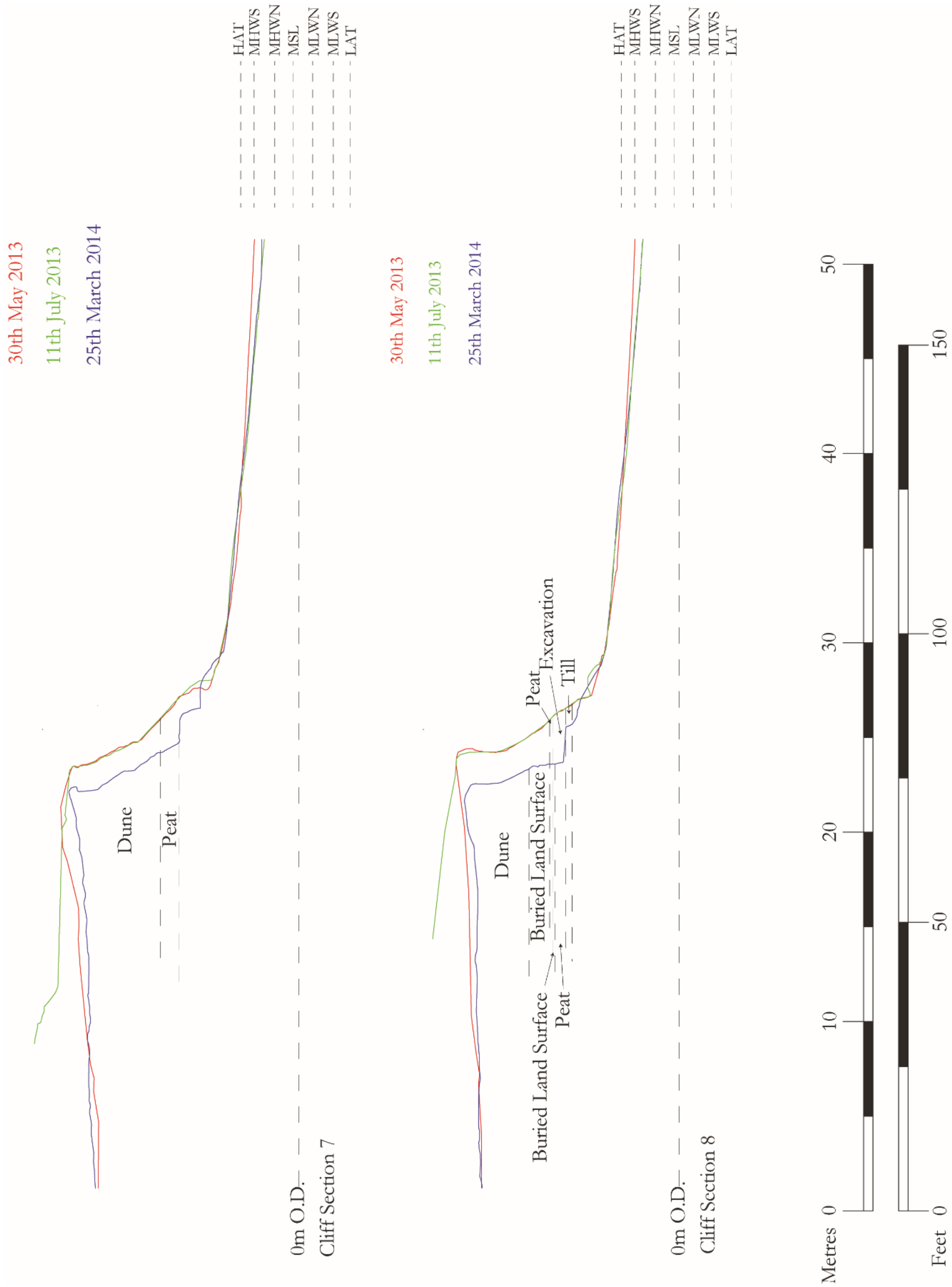

Figure 101 - Comparative cliff sections 5 & 6 (1.5x vertical exaggeration).

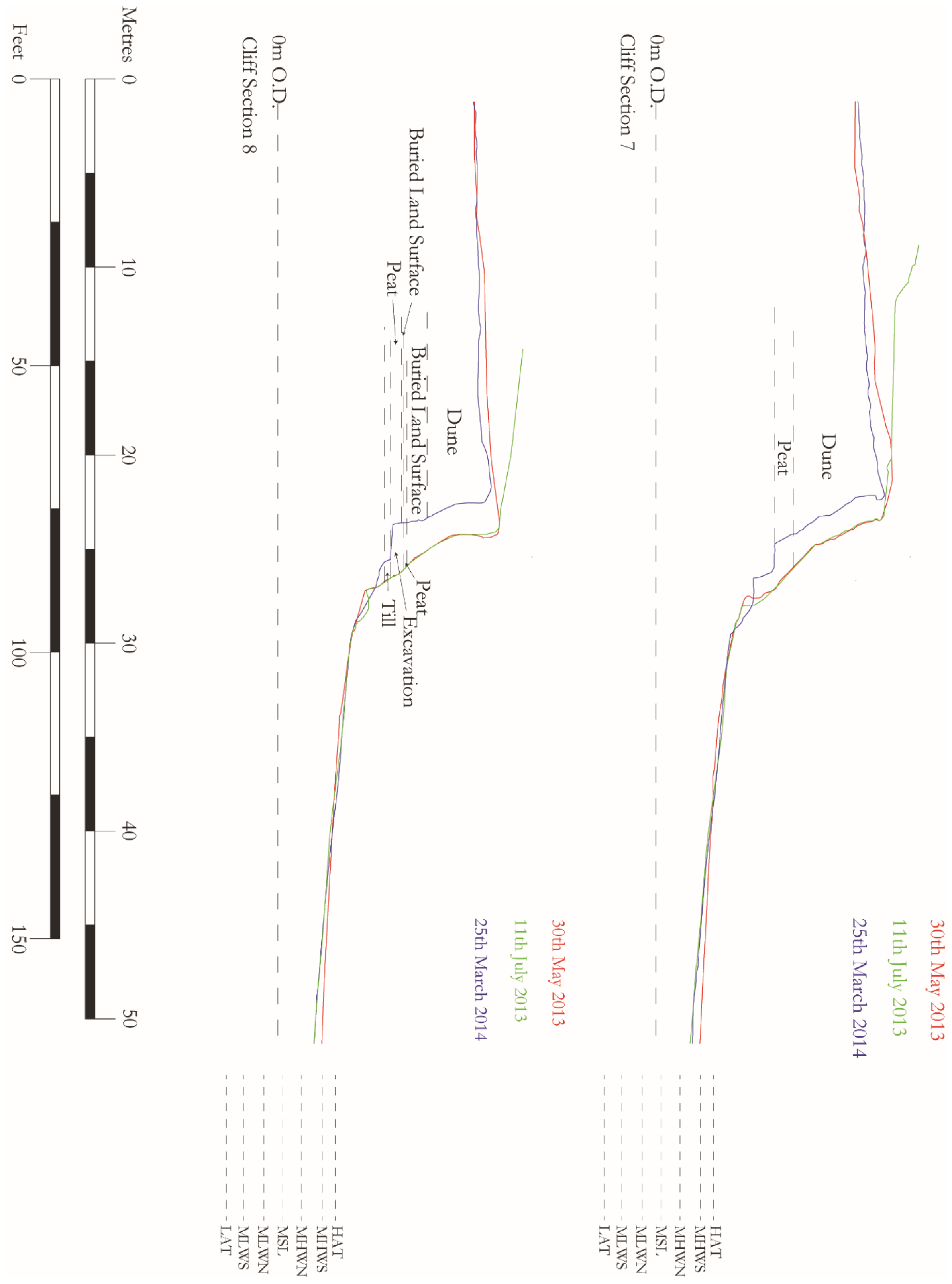

Figure 102 - Comparative cliff sections 7 & 8 (1.5x vertical exaggeration).

The sections show clear changes between each phase of survey, with the most notable change occurring between the second and third surveys (July 2013-March 2014). This is partly due to the much longer interval between the surveys, but can mainly be attributed to the effects of the winter storms. Two chief processes can be noted as occurring between surveys. Firstly, there is erosion to the cliff face, with the greatest impact being on the clifftop. Secondly, at the base of the cliff, there is a degree of sediment accumulation in the areas worst affected by the winter storms (Sections 7 & 8, Figure 101). This can be explained by the loss of material from the cliff face coalescing at the base of the cliffs. By comparison, the remainder of the foreshore shows a degree of beach lowering typical of the winter period.

Notably, changes can be seen to be occurring within different sediment types, with the greatest contrast occurring at the interface between the peat and the till (Sections 6, 7 & 8, Figures 100 & 101). The heavily compacted land surfaces which underlie the main excavation site appear to have weathered at much the same rate as the till, with the reconstituted material used as backfill after the excavation likewise eroding at a similar rate. As the overlying dune deposits are above the reach of the highest tides, it is the erosion of the lower deposits that defines the recession of the overlying dune system, therefore the areas of dune underlain by peat have a higher erosion rate than the archaeology site, buried land surfaces and reconstituted material.

The highest rates of recession appear to be at either end of the cliff section (Sections 1, 7 & 8), this is partly due to the location of the cairn on a localised rise (providing higher cliff sections), but may also reflect the more compacted nature of the underlying material.

8.4.2 Three-dimensional modelling using CloudCompare

The datasets from the first and last surveys were also imported into CloudCompare software, allowing the differences between these two surveys to be calculated and visualised in detail in 3-dimensional space. Prior to comparison both datasets were decimated to an average point spacing of 5cm. The reduction of the dataset was necessary to facilitate a faster computation and to eliminate any complications resulting from differing densities of data points. Despite the significant reduction in resolution, at a landscape survey level 5cm spacing is still considered extremely detailed (Bowden 1999). The initial comparison used the entire extent of the survey, enabling the visualisation of change to the site as a whole. This meant that all processes that affected the topography of the site and environs in the time between the two surveys could be detected. For example, there was a positive advancement in the areas surrounding the site boundary, where the spoil created during the course of the excavation had been dumped. In the area covered by the excavation itself, there was a slight lowering of ground level, in the main part this was due to the compaction of material during backfill, and also reflects the much lower vegetation which had not yet regrown on the site. Across the site as a whole fluctuation in vegetation accounts for some of the most notable change, there are pronounced changes at the rear of the site, both positive and negative, which have been caused by the change in vegetation along the edge of the Hauxley Reserve. A slight advance can be seen at the top of the cliff edge, where grasses have begun to overhang the clifftop. Interestingly, the general vegetation cover on the dunes themselves does not appear to have significantly changed, as both surveys took place at similar times of year, it can be implied that there was no significant advance in the amount of vegetation cover. On the cliff face itself, the erosion is particularly clear, with the contrast between the erosion rates of the different sediments being clearly visible. The area directly to the north of the site where the peat beds are located can be seen to have eroded to a much higher degree.

A more confined area of the site was then compared, which looked only at the area along the edge of the cliff face, in order to calculate a mean recession rate for the cliffs. This cropping of the data eliminated factors such as the changing vegetation from the final statistics. The comparison gave a mean difference of -0.421m for the cliffs as a whole, which is directly comparable to the -0.4m rate predicted in the Shoreline Management Plan (Guthrie *et al.* 2009).

8.5 Using Terrestrial Laser Scanning to Monitor Erosion

The use of terrestrial laser scanning at Low Hauxley has demonstrated the ability to monitor the rate of erosion and its effects on specific deposits at coastal archaeology sites. This data can then be used to provide evidence-based estimates of the risk to archaeological and palaeoenvironmental deposits set back from cliffs along this and other coasts under both present conditions and also future climatic scenarios. This information can then be used in the management of the archaeological resource along the coastline, as well as feeding into wider schemes of Integrated Coastal Zone Management.

The comparative survey of the cliffs at Low Hauxley shore indicates a mean rate of recession of 0.421m over a 299-day period. This is slightly above the baseline erosion rate of 0.4m/year given in the most recent Shoreline Management Plan (Guthrie *et al.* 2009), a difference which can be attributed to the unusually stormy nature of the winter period of 2013-2014. Importantly, the comparative survey illustrates the link between the recession and the stratigraphy of the cliff face, with the peat and buried land surfaces forming a bench and limiting the rate of erosion of the dunes above. The comparative survey also shows the different rates of erosion occurring on individual sediments. The resulting measured rate of cliff retreat can be extrapolated to under similar weather conditions the slight knoll on which the cairn was constructed would have been eroded back to the landward edge of the cairn in only 25 years. Prior to the excavation concern was raised that the intervention may destabilise the dune system at this point. As has been demonstrated by this study, the area of the site has eroded less than the area directly to the north, the difference in these rates being attributable to the sediments underlying the dune system, rather than as a result of the archaeological investigations. The prominence of the archaeological site caused by harder underlying material follows the model suggested by Poulton *et al.* 2006 (See Figure 103 below), with embayments forming to either side of the archaeology site. Whilst this would mean that the site was initially less at risk than the surrounding material, the remaining prominence would eventually have collapsed at a much faster rate, removing the archaeology with it. The decision to intervene archaeologically can therefore have been shown firstly to have been fully warranted as the site was at great risk and secondly to have caused no damage to the stability of the dunes.

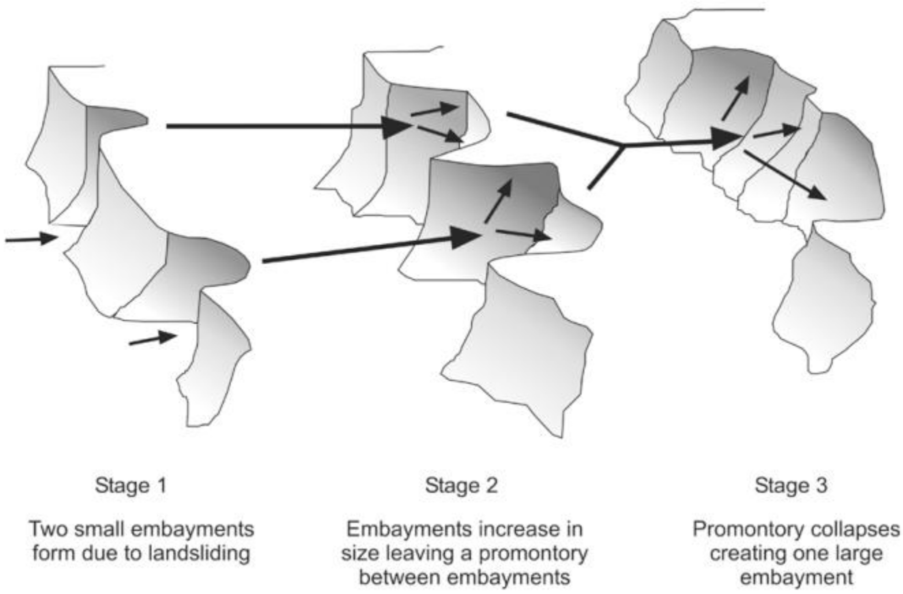

Figure 103 – Diagram showing the process of cliff erosion through creation of embayments (Poulton *et al.* 2006).

The use of terrestrial laser scanning at Low Hauxley has provided several key benefits. Firstly, TLS provided a valuable method of recording the heritage at risk prior to its destruction by erosion, and is of particular value of this site, which was 100% excavated as part of preservation by record. Secondly, the mechanisms of erosion and their effect on specific archaeological and palaeoenvironmental deposits could be measured by this technique. Not only was the information provided by the TLS able to replicate traditional outputs in the form of cliff sections, but it had the additional benefit of allowing more flexibility and a much higher level of detail in the production of these drawings. In addition, a much more complete comparison of the surveys was achieved through the use of CloudCompare, which allowed not only statistical analysis to be carried out, but also the visualisation of the dataset as a whole, allowing a much greater comprehension of the pattern of erosion at the site. Both forms of comparison contribute to the understanding of erosional processes at the site, the two-dimensional cliff sections highlight the erosion occurring on specific deposits at the cliff face but is limited to specifically chosen transects, whilst the three-dimensional comparison gives a wider context for the change, and a numerical value for the rate of erosion across the site but does not allow for the separation into specific deposits. It could be argued that the three-dimensional model is of greater use in predictive modelling, whilst the two-dimensional sections provide the type of information needed for the long-term management of the site in terms of its archaeological and palaeoenvironmental deposits. The TLS surveys can also be used to form a baseline record for future survey. The level of detail and accuracy achieved on these surveys through the use of TLS mean that further surveys of the same area can be directly compared, allowing further monitoring of the deposits at Low Hauxley to take place. It is also important to note that the use of TLS at Low Hauxley was intended to satisfy a range of concerns from the numerous parties involved with the site and its environs. This is an increasingly salient feature in coastal archaeological work, as large sections of coast increasingly fall under protective designations from a range of different conservation bodies, and an approach that can inform a number of different policy bodies on the long term management and feed into Integrated Coastal Zone Management plans of the dune system is of tremendous value

Some criticisms can be made of the approach used at Low Hauxley. Firstly, Low Hauxley can in many ways be considered an optimum site for fieldwork of this type. There were good lines of sight across the area, the topography was that of low cliffs with an easily accessible foreshore, and there were many locations both on the beach and the dunes were permanent ground control could be easily established, facilitating a high degree of accuracy between surveys. Large hard rock cliffs would have been a much different challenge, although it should be noted that they erode differently and also have a very different archaeology so in any case would have necessitated a much different approach. Likewise, the extent of the survey at Low Hauxley was limited to an area of around 150m by 150m; a wider survey of the coastline would have required a different approach, with more rigorous controls. This study also emphasises the importance of that comparative survey using TLS or any other means is a far from automated process. Factors such as vegetation, archaeological investigations and seasonal variation all influenced the results of the comparison, and knowledge of the site and conditions was necessary to account for these changes. These criticisms, however, are limited to the operational side of the approach. The comparison of the data clearly shows the validity of the methodology, which could be applied of sites and structures within the coastal and intertidal zones.

Low Hauxley is an unfortunate example of a heritage at risk site that has been known to have been actively eroding for thirty years. A long-term strategy for monitoring erosion at the site was developed as early as 1994, using the newest and most accurate equipment available. Sadly, the opportunity to pursue this approach (which recorded both top and bottom of the cliffs as well as the deposits in section) was missed, which would have greatly increased our knowledge on the erosion of significant deposits, and helped formulate strategy for the long-term management of the site. The methods used in this case study prove the validity of such an approach, and whilst the level of erosion detected over the 2013-14 period was atypical, the principle can be clearly proven.

Chapter 9: Discussion & Conclusions

The emergence of new survey technology means new capabilities in data collection and processing, which requires new methodologies guided by new theoretical approaches. It could be argued that terrestrial laser scanning is not a new technology, but rather the evolution of existing systems of data collection through the use of laser measurement and trigonometry, technology already found in total stations. What is new however, is the speed, accuracy, and sheer volume of information provided by the equipment. The ability to bridge the gap in scale between accurate and detailed recording of objects and their immediate landscape from millimetres to hundreds of metres in range is unique in the field of metric survey. In addition, the fact that the equipment offers full three-dimensional recording and an ability to integrate with other forms of technology, both in fieldwork and in processing, is tremendously advantageous. The fact the technology has been in use for nearly fifteen years could preclude the use of the term new, but the increased portability of the kit has greatly increased the flexibility of the technology, meaning that it now presents a viable alternative to other forms of survey. It is essential to consider emerging techniques not merely in terms of their technology but as a holistic system, the technical aspects of how they work combined with their logistical deployment in the field and the ability to process, visualise and interpret the data after collection. Terrestrial laser scanning has not greatly altered in terms of principle since its inception, but has radically changed in its operational abilities moving from fixed aspect sensors requiring several pieces of supporting technology, to small portable units with integral power and processing capabilities. It is this change that has facilitated its use as a survey instrument proper, and enabled it to function in the field as an alternative to total station or GNSS survey.

Despite all of these technological advances what has not changed in archaeological fieldwork is the way in which it has been applied. Very often terrestrial laser scanning survey is commissioned as an afterthought, or used to record in high detail a specific structure, with no attempt to look at the wider applications of the equipment. As has been demonstrated in the work at Aust (Chapter 4), the ability to integrate the results of the survey with wider landscape data moves the technology beyond the level of a site based record with little additional effort required. However, the stage at which terrestrial laser scanning should be employed on a site still needs to be considered. The example of Emsworth (Chapter 6) has shown that terrestrial laser scanning is not particularly useful as a prospection tool; indeed, the very notion of any form of prospection can be questioned, given the challenges of any form of archaeological prospection the coastal and intertidal zone.

In seeking to use the equipment to develop new methodologies for the recording of archaeology in the coastal, and in particular the intertidal zone, what has been most surprising is the lack of existing methodologies, or standards in the way these unique landscapes are approached. Unlike wetland archaeology sites, underwater archaeology sites, or terrestrial sites and monuments, very little guidance exists in how the coastal and intertidal zones should be considered, explored and recorded. In part this is due to their existence as a fringe landscape. The lack of policy and regulation that cover these areas has meant that, unlike terrestrial or offshore landscapes, there has been a dearth of developer-led funding and mitigation to promote the development of guidelines. Aspects of the coast such as ports and harbours have been considered as 'historic seascapes' and guidance documents produced, but these often amount to cultural studies rather than practical guides. The tendency is still to see the coastal and intertidal zones as extensions of the terrestrial sphere. What guidance does exist in terms of fieldwork and survey tends more to emphasise the health and safety aspects of project planning. As a result, while a number of solid archaeological surveys have taken place these have fallen back on the standards and practices developed for terrestrial archaeology, and have not sought to recognise the additional factors which make the coastal zone unique. In particular, relative sea level and the key importance of the tidal frame (both past and modern) on coastal and intertidal sites requires the accurate recording of elevation and the ability to relate said elevations to tidal processes. As demonstrated at le Yaudet (Chapter 5) this is important for understanding the possible functions of sites in relation both to each other and to the landscape. The work at Low Hauxley (Chapter 8) has also emphasised the importance of the modern tidal frame on eroding sites, and the effect of enhanced storminess and relative sea level rise on threatened coastal archaeology sites.

It could, however, be argued that terrestrial laser scanning enables new approaches, although again, the use of the term 'new' could be argued. Key to the application of terrestrial laser scanning survey is an understanding of metric survey as a whole, not merely in the technical sense of understanding the technology or underlying mathematical principles, but in the approach taken in its application. Underlying all of measured survey is the ideal that the survey is guided by the research questions being asked. What is new in the approach suggested by this thesis is the ubiquitous nature of the data. Whilst there is no such thing as truly objective survey (the very act of conducting a survey being a subjective choice), the sheer amount of data gathered by the equipment removes some of the choices made in the resolution and coverage of surveys. In fact, the way in which terrestrial laser scanners function means that it is as easy, if not easier to collect more widespread survey. This extraneous data would be burdensome were it not for the parallel development of software to allow for filtering and reduction of data. What this results in is a dataset that is not only appropriate to the objectives of the survey, but has the potential to be useful for a number of additional applications. Thus a detailed scan of an excavated feature (such as those in Chapters 5 & 7) will also record and visualise the landscape context of the feature. Terrestrial laser scanning survey therefore has a 'value added' factor. The survey of the site at Low Hauxley (see previous chapter) was not originally conceived as a coastal monitoring project, yet the quality of the data produced in terms of its resolution and accuracy meant that it could easily be turned to this purpose. Subjectivity is often lauded in metric survey (e.g. Blake 2010), and indeed an underlying principle of all measured survey is that the resolution, accuracy and precision are tailored to the aims of the survey. However, the increased ability to collect, store and process such data means that these choices can often be made post-collection. This does not preclude the need for a tightly defined brief, justify excessive data collection, or de-necessitate an informed archaeological input but does mean that there is the potential for using data collected for a specific application for more than one purpose. In addition, the conversion of the data to solid surfaces for modelling and volumetric analysis (such as that seen in Chapter 8) adds a valuable new dimension to the study of archaeological sites, both in being more objective and more detailed than the human eye and in being able to collect and process a level of information which is difficult to attain through other methods.

9.1 Applying Terrestrial Laser Scanning to Coastal and Intertidal Archaeology

Any approach that studies archaeology in the coastal and intertidal zones requires high resolution in order to record diagnostic detail at an appropriate level. It requires a high level of accuracy, so that important structural details such as sills and sluices can be accurately placed within the tidal frame, but also so that monitoring of erosion can reliably be detected. The nature of the landscape also demands a high speed approach to survey. Most importantly, the technology used must be appropriate to the questions being asked of the landscape, and be able to record information at a level that supports and informs fieldwork. In developing the use of terrestrial laser scanning in the coastal and intertidal zone, a 'best practice' methodology was proposed to answer these demands (See Section 3.6). To test the methodology, a range of case studies were developed. The survey at Aust, Gloucestershire (Chapter 4) demonstrated how the data from terrestrial laser scanning can easily be integrated with other forms of metric survey and mapping data to increase the potential of the dataset. Work in the Léguer estuary (Chapter 5) looked at the ability of the technology to answer questions about the interpretation of intertidal archaeology sites, through reference to the tidal frame, and volumetric analysis of structures. A survey of the foreshore at Emsworth, Hampshire (Chapter 6) used the three-dimensional data gathered by the scanner as a framework for accurately placing non-metric data within a detailed topographical model. Recording of the structure at Medmerry on Selsey Bill, West Sussex (Chapter 7) tested the ability of the approach within a standard archaeological excavation, and proposed improved methods of recording complex archaeological structures under commercial pressures. Finally, repeat terrestrial laser scanning surveys of the site at Low Hauxley (Chapter 8) was used to examine the processes underlying the coastal erosion of archaeological features.

For the most part the outlined methodology provided a strong framework for these surveys, however, inevitably the implementation of such a methodology raised unforeseen issues and challenges. Many of the issues that were encountered in fieldwork are common to all coastal and intertidal work. Firstly, the coincidence of appropriate tidal conditions with appropriate working conditions defined and limited the work on site. Access to some sites at the lower end of the tidal range was restricted to periods of extreme spring tides, for example at sites in the Léguer estuary (Chapter 5). Appropriate tides do not always coincide with working hours, meaning that work in some places was restricted to only a couple of working weeks per year. The additional factor of weather conditions further complicates this picture, with poor weather rendering some forms of kit obsolete, this was seen both in the survey at Léguer (Chapter 5), where heavy rain disrupted the final day's fieldwork, but also in the survey at Emsworth (Chapter 6), where poor lighting conditions meant that the spectroradiometry of the foreshore was not possible.

The ability to georeference terrestrial laser scanning surveys to absolute controls is essential in order to relate features and structures to the tidal frame, and the limited window of fieldwork within the intertidal zone raises questions of the validity of survey which ran for more than one tidal cycle. Rather than being able to rely on georeferencing each day's work using GNSS, accurate registration of datasets necessitated ground control points to ensure a high degree of accuracy between surveys. Although these factors were foreseen in the methodology, their extent and impact upon the work was not fully realised in advance. An unforeseen factor that complicated the fieldwork was the impact of non-archaeological designations and conservation within the intertidal zone. Of the sites covered by this thesis Aust is within an area designated as a Special Area of Conservation, a Special Protection Area, a Natura 2000 site and a Ramsar site, whilst Aust Cliff immediately to the southwest is listed in the Geological Conservation Review and is a Site of Special Scientific Interest for its geology. Low Hauxley is likewise listed in the Geological Conservation Review and is a Site of Special Scientific Interest due to the nature of the palaeoenvironmental deposits, as well as being adjacent to an RSPB bird reserve. The Léguer estuary is a Natura 2000 site, and is under growing pressure to adopt additional protections to preserve and enhance its marine life. These designations had a direct impact on some of the surveys. Restrictions on site at Selsey Bill due to nesting plover prevented the survey of two of the excavated sections, whilst the initial purpose of the survey at Low Hauxley was to mitigate for the potential threat to the RSPB bird reserve posed by destabilising the dunes through excavation. An understanding and appreciation of the different priorities and protections that exist within the coastal zone is greatly beneficial in developing an approach to fieldwork within this environment. An additional unforeseen factor in the estuarine environments of Aust (Chapter 4) and Léguer (Chapter 5) was the significant effect that freshwater had on the stability of the equipment during survey, with the rising freshwater table preceding the incoming tide and further reducing the time available for stable and accurate survey.

None of the sites covered by this thesis disproved or invalidated the proposed methodological approach but rather emphasised the need for solid planning prior to fieldwork and the need for established guidelines and methodologies for approaching these unique and dynamic environments.

9.2 Conclusions

It is no longer sufficient for survey to be an afterthought in archaeological fieldwork. Most smart phones now contain technology to allow for GNSS recording down to a metric level, meaning that a very basic level of measured survey is possible by most archaeological fieldworkers. Survey can therefore be selected not on the basis of availability or expense, but on the appropriateness of the technology to the aims of the study. The aim of this thesis has been to develop a means of using terrestrial laser scanning to rapidly record intertidal structures within their immediate environs and to use that context to understand their construction and function. Terrestrial laser scanning is not the only survey technology that could be used in this approach. There is no one survey technique that can cover everything, there is no magic box. What this study has aimed to show is that the study of coastal and intertidal archaeology sites has questions at a multitude of scales and resolutions, because the nature of the structures cannot be differentiated from their immediate landscape context. Terrestrial laser scanning is not the definitive answer, but it is the best fit approach that allows these aims to be met and facilitates the integration of a wide range of additional approaches. Most importantly the use of terrestrial laser scanning places the understanding of landscape as the central element of the approach to coastal and intertidal archaeology.

Appendix A Tidal Ranges of Sites Used as Case Studies

Case Study	**Aust**	51° 36' N	2° 36' W
Standard Port	Port of Bristol (Avonmouth)	51° 30' N	2° 44' W
Secondary Port	Beachley (Aust)	51° 36' N	2° 38' W
Chart Datum offset	-6.10m below Ordnance Datum (Newlyn)		
Tidal Range	12.3m		

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Chart Datum	-00.32	+00.70	+03.30	+06.42	+09.60	+13.00	+14.50
OD Newlyn	-06.42	-05.40	-02.80	+00.32	+03.50	+06.90	+08.40

Table 17 – Approximate Tidal Heights of Aust site

Case Study	**Léguer**	48° 44' N	03° 32' W
Standard Port	Roscoff	48° 43' N	03° 58' W
Secondary Port	Locquemeau	48° 44' N	03° 35' W
Chart Datum offset	-4.92m below IGN69		
Tidal Range	7.85m		

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Chart Datum	+00.17	+01.30	+03.45	+05.38	+07.30	+09.15	+10.06
IGN69	-04.75	-03.62	-01.47	+00.46	+02.38	+04.23	+05.14

Table 18 - Approximate Tidal Heights of Léguer site

Case Study	**Medmerry**	50° 44' N	00° 49' W
Standard Port	Portsmouth	50° 48' N	01° 07' W
Secondary Port	Selsey Bill	50° 44' N	00° 47' W
Chart Datum offset	-2.9m below Ordnance Datum (Newlyn)		
Tidal Range	4.8m		

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Chart Datum	-00.17	+00.60	+01.80	+02.92	+04.10	+05.40	+05.70
OD (Newlyn)	-03.07	-02.30	-01.10	+00.02	+01.20	+02.50	+02.80

Table 19 - Approximate Tidal Heights of Selsey Bill site

Case Study	**Emsworth**	50° 50' N	00° 56' W
Standard Port	Chichester Harbour (Entrance)	50° 47' N	00° 56' W
Secondary Port	Northney	50° 50' N	00° 58' W
Chart Datum offset	-2.74m below Ordnance Datum (Newlyn)		
Tidal Range	4.4m		

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Chart Datum	-00.34	+00.50	+01.70	+02.74	+03.80	+04.90	+05.30
OD (Newlyn)	-03.08	-02.24	-01.04	+00.00	+01.06	+02.16	+02.56

Table 20 - Approximate Tidal Heights of Emsworth site

Case Study	**Low Hauxley**	55° 18' N	01° 33' W
Standard Port	River Tyne (North Shields)	55° 00' N	01° 26' W
Secondary Port	Amble	55° 20' N	01° 34' W
Chart Datum offset	-2.65m below Ordnance Datum (Newlyn)		
Tidal Range	4.2m		

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Chart Datum	-00.10	+00.80	+01.90	+02.92	+03.90	+05.00	+05.70
OD Newlyn	-02.75	-01.85	-00.75	+00.27	+01.25	+02.35	+03.05

Table 21 - Approximate Tidal Heights of Low Hauxley

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