THE MESOLITHIC LANDSCAPE OF THE SOUTHERN NORTH SEA

By

SIMON FITCH

A thesis submitted to
The University of Birmingham
For the degree of
DOCTOR OF PHILOSOPHY

Institute of Archaeology and Antiquity
College of Arts and Law
The University of Birmingham
June 2011

UNIVERSITY OF BIRMINGHAM

1st of 3 files

Main thesis

Appendices 1-3
are in an additional file

Appendix 4 is
in a separate zip folder

ABSTRACT

The submerged landscape of the North Sea has long been known by archaeologists as an area of Mesolithic occupation, and it has even been argued that it was the 'heartland' of the Mesolithic in North Western Europe. Despite knowledge of the potential significance of the marine archaeological record, it has always been a great challenge to explore this largely inaccessible landscape and in many ways it remained a hypothetical construct. However, recent research in the Southern North Sea has recently permitted the mapping of parts of this landscape, revealing the scale and diversity of submerged Mesolithic environments. This research represents a "first pass" study that has produced an initial model of the carrying capacity of the landscape and its associated demography. This model seeks to explore the impacts of sea level driven landscape change upon the Mesolithic population. The model reveals the diversity of resources present in this landscape and the potential these have to buffer subsistence resources from the effects of marine inundation. As such the model provides new insights into the nature of the impacts upon human occupation within the region and highlights 8,500BP as a crucial time in the evolution of the Mesolithic in north western Europe.

<u>DEDICATION</u>

This thesis is dedicated to the memory of

Dr. Ken Thomson

Friend and Colleague

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

APPENDIX FIGURES

LIST OF TABLES

NOTE: ALL OVERSIZE WHOLE STUDY AREA MODEL OUTPUT TABLES AND CATCHMENT ANALYSIS OUTPUT TABLES ARE AVAILABLE IN DIGITAL FORM IN APPENDIX 4

LIST OF DEFINITIONS

ALSF – Aggregates Levy Sustainability Fund

Atlantic - a European climatic period dating to c. 8,000 to 5,000 BP. This was the warmest and moist period of the Holocene in northern Europe and generally warmer than today. As the warmest period of the Holocene the Atlantic is often referred to as the Holocene climatic optimum.

BGS - British Geological Survey.

Boreal - a European climatic period dated to c. 10,000 to 8,000 BP. In peat bog sediments, the Boreal is also recognised by its characteristic pollen assemblage.

Holocene - the geological epoch beginning 10,000 BP to the present. The Holocene is part of the Quaternary Period. This period is intimately connected with the rise of modern human civilisations.

Moorlog - a term applied by North Sea trawler men to lumps of peat recovered in their nets from the sea floor.

NSPP - North Sea Palaeolandscape Project

PGS - Petroleum Geo-Services (www.pgs.com).

Pleistocene - a geological epoch dating 1,800,000 to 10,000 years BP and associated with the world's recent period of glaciations. It is succeeded by the Holocene epoch. The end of the Pleistocene corresponds with the end of the Palaeolithic age used in archaeology.

Quaternary - a geological time period following the Pliocene and lasting from c. 1.8 million years ago to the present. The Quaternary includes 2 main subdivisions: the Pleistocene and the Holocene.

Remote Sensing - generally involves the acquisition of information of an object or phenomenon, by the use of a sensing device that is not in physical contact with the object. This may mean the device is housed in an aircraft, satellite or ship.

Storebaelt or *Great Belt* - one of three straits in Denmark that connect the Kattegat to the Baltic Sea. The others are Oresund and Little Belt, which are smaller. The Storebaelt is c. 60 kilometres long and 16-32 kilometres wide and surrounds the two major islands: of Sprogø in the north and Langeland in the south.

Upper Palaeolithic the period between 40,000 and 10,000 years ago, when stone tool assemblages made by anatomically modern humans (*Homo sapiens sapiens*) appeared in Britain.

UKOOA - United Kingdom Offshore Operators Association

CO-ORDINATE SYSTEMS UTILISED WITHIN THIS THESIS.

Within the GIS project used for this thesis a UTM Zone 31N Projection System was utilised. Positions and GIS shapefiles obtained from other institutions were converted to this projection using the Geospatial tools within ArcGIS 9.1.

DATING SYSTEM

Dates in this thesis are present as uncalibrated BP (before present) unless otherwise stated. It is important for the reader to understand that the present (using the BP system) is defined as AD1950.

CHAPTER 1

THE MESOLITHIC LANDSCAPE ARCHAEOLOGY OF THE SOUTHERN NORTH SEA

1.1   Introduction

The North Sea could be considered one of the most inspirational, but, at the same time, one of the most problematic subject areas for landscape archaeology, especially in relation to the area of Mesolithic research. In recent years there has been a growing interest in the archaeological potential of the European coastal shelves. This has been driven by the development of the subject of submerged prehistoric landscapes which is aimed at exploring the settlement and cultural sequences of the immense, prehistoric landscapes that lie off our coasts (Bailey *et al.* 2010, Peeters *et al.* 2009). However, the marine environment which transgressed these landscapes has also hindered both the investigation and sampling required for research in this area. This is a significant issue as it is increasingly understood that many aspects of early prehistoric settlement across north western European are not truly comprehensible without an adequate understanding of these unexplored regions (Bailey *et al.* 2004). The need for a new marine research agenda to provide this is therefore required (COWRIE 2010, Bell 2010, Bailey *et al.* 2010).

Despite these recent developments, the few archaeological sites known in the littoral region (e.g. Momber (2004), Lubke (2003), COWRIE (2010), Fischer (1995)) show a preservation and range of materials that clearly rivals sites found on land (Verhart 1995). It may therefore appear surprising that the potential of the marine archaeological record was rarely appreciated, even within the discipline, prior to the last twenty or so years. The

opportunities presented by marine sediments to inform our knowledge of the human occupation of the British Isles from the last ice age is fairly self evident. Indeed, for much of this time, mainland Britain was not actually an island but a peninsula of the contiguous continental land mass (Coles 1998, Stringer 2006). Reconstruction of the nature and pace of this changing landscape is, however, complex and contested. A number of competing models are frequently cited within the literature and include Coles (1998), Jelgersma (1979), Lambeck (1995) Peltier *et al.* (2002), and Shennan *et al.* (2000; 2002). However, these studies tend to generate data that are relatively coarse and concern has been expressed as to the adequacy of the output for the requirements of archaeological landscape reconstruction (Bell *et al.* 2006, Ward and Larcombe 2008).

Archaeologically, there are equally difficult interpretational issues relating to these emergent plains. In most instances the lack of evidence for settlement, and the unlikely success of exploration, has led to the marginalisation of the area within the literature. Indeed, the lack of this information has produced an unconscious bias within the archaeological community, which often considers the marine sphere "distant" or "difficult" to the point where these regions are excluded from reconstructions and archaeological analysis (Bailey 2004). Understanding the archaeology of this period is therefore a major challenge (Bailey *et al.* 2010, Dix *et al.* 2004). However, the available evidence hints that substantial deposits and evidence may be preserved within the marine environment. Data includes individual finds from as far north as the Viking Banks (Long *et al.* 1986) and significant concentrations of archaeological and palaeoenvironmental finds in the southern North Sea (Reed 1913; Louwe Kooijmans 1970) and submerged sites including that at

Bouldnor Cliff in the Solent (Momber 2000). It is disconcerting, however, to consider that, with the exception of Bouldnor Cliff, few of these can be considered as little more than isolated stray finds (Kooijmans 1970, 1971).

Given this situation it is not surprising that there has been relatively little appreciation that marine areas could support a resource-rich landscape that had been available for settlement. Yet these areas may have been more attractive for occupation than the terrestrial zones that have provided much of our data. The relict landscapes identified in the southern North Sea are so large that it cannot be certain that the societies that inhabited these regions may be directly comparable to those attested within terrestrial contexts (Gaffney *et al.* 2009). These landscapes, therefore, offer new and intriguing opportunities for exploration and discovery not faced by terrestrial archaeologists. The areas under investigation are supranational in scale and can be masked by tens of metres of water and sediment (Fitch *et al.* 2005). This exceptional archaeological resource provides those archaeologists who wish to explore the landscape, with a unique set of technical and methodological challenges. It is perhaps no wonder that one reviewer recently suggested that exploration of the inundated landscapes that exist across the globe may well prove to be one of the last great challenges for archaeology (Bailey 2010). A major step forward in understanding the enigmatic prehistoric landscape was made possible through Aggregates Levy Sustainability Fund (ALSF) funded research at Birmingham University (UK) 2007 which utilised 3D seismic sets, captured for commercial purposes, to explore these landscapes. The North Sea Palaeolandscape Project (here after referred to as NSPP) provides landscape information from areas surrounding the thesis area, and has also greatly advanced the

scientific understanding of the British side of the southern North Sea. An atlas of the NSPP results is provided in Appendix 3 to assist the reader in contextualising the thesis. In archaeological terms, the mapping programme, which covered some 23,000km^2, constituted the largest contiguous archaeo-geophysical survey programme ever attempted globally at that time.

Whilst the NSPP represents a major advance in the technical location of broad landscape features and the application of new technologies to 3D seismic data, the project did not seek to investigate the scale and nature of Mesolithic occupation within the region. Additionally, the impacts of landscape change throughout the Mesolithic occupation period were not explored. This thesis, therefore, seeks to go beyond the results of the NSPP by investigating these unresolved questions. Due to the scarcity of information, direct exploration of Mesolithic occupation of this landscape has yet to be performed. However, as a consequence of the increase in information on the surrounding landscape from the North Sea Palaeolandscapes Project (NSPP), a variety of data is now available to this thesis to allow an initial quantitative analysis of the potential nature and scale of human occupation of this landscape.

This thesis intends to produce a "first pass" study with the aim of producing an initial model of the carrying capacity of the landscape and its associated demography. The level of data is still such that these would be indicative rather than real values, as they incorporate only an indication of the ecological factors affecting population density. It thus ignores the complex social behaviours of hunter-gatherer societies which would also influence this.

Since there is a lack of even basic archaeological information, the utilisation of a model of the occupation of this region in such a manner would, therefore, have a real and significant value.

With this in mind, the purpose of this thesis is to use archaeological science to explore the impacts of landscape change upon the Mesolithic population to produce testable hypothesis for future research. This will be achieved through the generation of an archaeological model. The model will utilise available landscape data to examine the landscape and its environment to provide insight into the nature and magnitude of the impacts upon the human occupation within the region. The principle questions for which resolution is sought by this thesis are therefore summarised below as a series of aims and objectives.

Aim 1: To generate physical landscape data and environmental change across it.

Objective 1.1: To generate topographic data and identify topographic key features from 3D seismic data.

Objective 1.2: To identify key landscape features within the 3D seismic data.

Objective 1.3: To generate a suitable soils dataset from the available mapping and 3D seismic data.

Objective 1.4: To generate mapping of tree colonisation of the study area over time

Objective 1.5: To apply sea level curve data to the data generated by the above objectives (1.1 to 1.4) to simulate inundation.

Aim 2: To use the data generated in **Aim 1** to create models of potential past human resource use and population.

Objective 2.1: To generate a model of food resources for the terrestrial and marine areas.

Objective 2.2: To determine the possible resource yield of these food resources to a human population.

Objective 2.3: To identify areas which would have been favourable to human habitation and determine their catchment area.

Objective 2.4: To determine the resources present within the catchment area determined by **Objective 2.3**.

Aim 3: To examine the effects of sea level change on the potential for past human subsistence within the study area.

Objective 3.1: To evaluate the physical loss of landscape and the associated landscape features.

Objective 3.2: To examine the change in food resource availability due to sea level change.

Objective 3.3: To consider the impact of landscape loss and resource availability at both catchment and a wider study area scale upon the human population levels.

Objective 3.4: Discuss the impacts of these changes upon a human population within their wider context.

1.2   The study area

Physically, the southern North Sea occupies a position between the European countries of Denmark, Germany, The Netherlands, Belgium, France and the United Kingdom, and is confined in latitude between 55 degrees north and the 51 degrees north. Of this, the British sector of the southern North Sea covers some 62,000 km^2, with depths within the southern North Sea ranging from 15m at the Dogger Bank to 80m in the north and within the Outer Silver Pit region. The area modelled as part of this thesis ranges in depth from 20m in the north of the survey area to 80m in the Outer Silver Pit. This region owes its appearance largely to Pleistocene glacial erosion and Holocene deposition which would have formed the Mesolithic landscape. However, it is important to remember that the longer geological history of the area has exerted an influence on the formation of the landscape of the area.

The area to be considered by this study lies within British waters, in a location close to the median line between Britain and the Netherlands. The area covers some 4,500km^2 extending from the top of Doggerbank, crossing the Outer Silver Pit and terminating on its southern flank.

This study is based primarily upon data provided specifically for this study by PGS UK Ltd. The data, a subset of the southern North Sea Mega Merge (PGS 2005), comprises of a series of 3D seismic surveys welded together to produce megasurvey blocks. In this thesis blocks J08 and J07 were utilised (see Figure 1.1), which were selected on the basis of their data quality and possible location within an emergent Mesolithic landscape.

The data forming these blocks is of a variety of vintages, but primarily is composed of airgun data collected with multichannel streamers at the end of the 1990s. Whilst of a standard resolution, these data are ideal for extensive landscape survey (see Fitch *et al.* 2005, Fitch *et al.* 2007). Additional data from around the study area is derived from the North Sea Palaeolandscape survey (Fitch *et al.* 2007, Gaffney *et al.* 2007) and will be utilised for this purpose in Chapter 5 of this thesis.

1.3 Geology of the study area and its geological history

The geological history of the area can be best examined by looking briefly at the deeper geology within the area that forms the basement (Table 1.1). The basement rocks of this region have produced broad scale effects that can be shown to have influenced the archaeological landscape throughout the Upper Palaeolithic and into the Mesolithic. The basement rocks also control the distribution of hydrocarbon resources within the area, and hence the economic activity which impacts upon the archaeology preserved in these regions.

The age of the basement in this region ranges from Upper Palaeozoic age, through the Mesozoic, and in some areas, into the relatively recent. As most research on these older rocks has primarily been commissioned by the oil and gas industry, the understanding of this geology is fairly good. However, the lack of oil deposits in recent deposits has restricted their study. There are many factors which would have influenced the landscape

of the Mesolithic, but the geological story of this area, at least in economic terms, begins at the Carboniferous period (360Ma to 290 Ma).

The rocks of the Carboniferous are reasonably well documented, despite the fact that they may be buried up to 4km in depth (Cameron *et al.* 1992). Their similarity to rocks found in the terrestrial record of eastern England greatly aids this understanding. Research by the oil and gas industry has led to the coal measures being regarded as the source rock for some of the gas deposits contained within the southern North Sea. Apart from their influence on the distribution of economic resources, Carboniferous rocks have little potential effect on the Holocene landscape due to their depth of burial and lack of outcrop. The overlying Permian rocks (290Ma to 250Ma) are, however, much more significant. The arid environment during their formation produced a series of evaporite deposits. These were formed by the drying out of a marine basin (Van Veen 1975). These evaporite deposits have produced widespread halokinetic deformation of the overlying younger units, including those which would have formed the Holocene landscape.

Prehistoric Archaeology Summary Table			
Geological Period	**Archaeological Period**	**Date**	**Deposits**
Mid to Late Holocene	Submerged (Neolithic onwards)	6 000 BP to Present Day	Terschellingerbank Member Indefatigable Grounds Formation, Modern Sediments
Early Holocene	Late Upper Palaeolithic/ Mesolithic	12 000 BP to 6 000 BP	Elbow Formation
Earliest Holocene/ Late Pleistocene	Late Upper Palaeolithic	20 000 BP to 12 000 BP	Botney Cut Formation
Late Pleistocene	Upper Palaeolithic/ Late Middle Palaeolithic	50 000 BP to 16 000 BP	Well Ground Formation, Dogger Bank Formation
Middle Pleistocene	Lower Palaeolithic	420 000 BP to 375 000 BP	Egmond Ground Formation
Middle Pleistocene	Lower Palaeolithic	420 000 BP to ?	Sand Hole Formation
Middle Pleistocene	Lower Palaeolithic	475 000 to 420 000 BP	Swarte Bank Formation (Tunnel Valleys)
Early Middle Pleistocene	Lower Palaeolithic	700 000 to 475 000 BP	Yarmouth Roads Formation
Lower Pliestocene	N/A	2.3Ma to 700,000BP	Deltaic Deposits
Tertiary	N/A	65Ma to 2.3Ma	Tertiary Mudstones
Cretaceous	N/A	140Ma to 65Ma	Upper Cretaceous Chalk
Jurassic	N/A	210Ma to 140Ma	Limestones and Mudstones
Triassic	N/A	250Ma to 210Ma	Forbes Field Sandstone
Permian	N/A	290Ma to 250Ma	Evaporites
Carboniferous	N/A	360Ma to 290Ma	Coal Measures

Table 1.1 Geological Key of the Study area
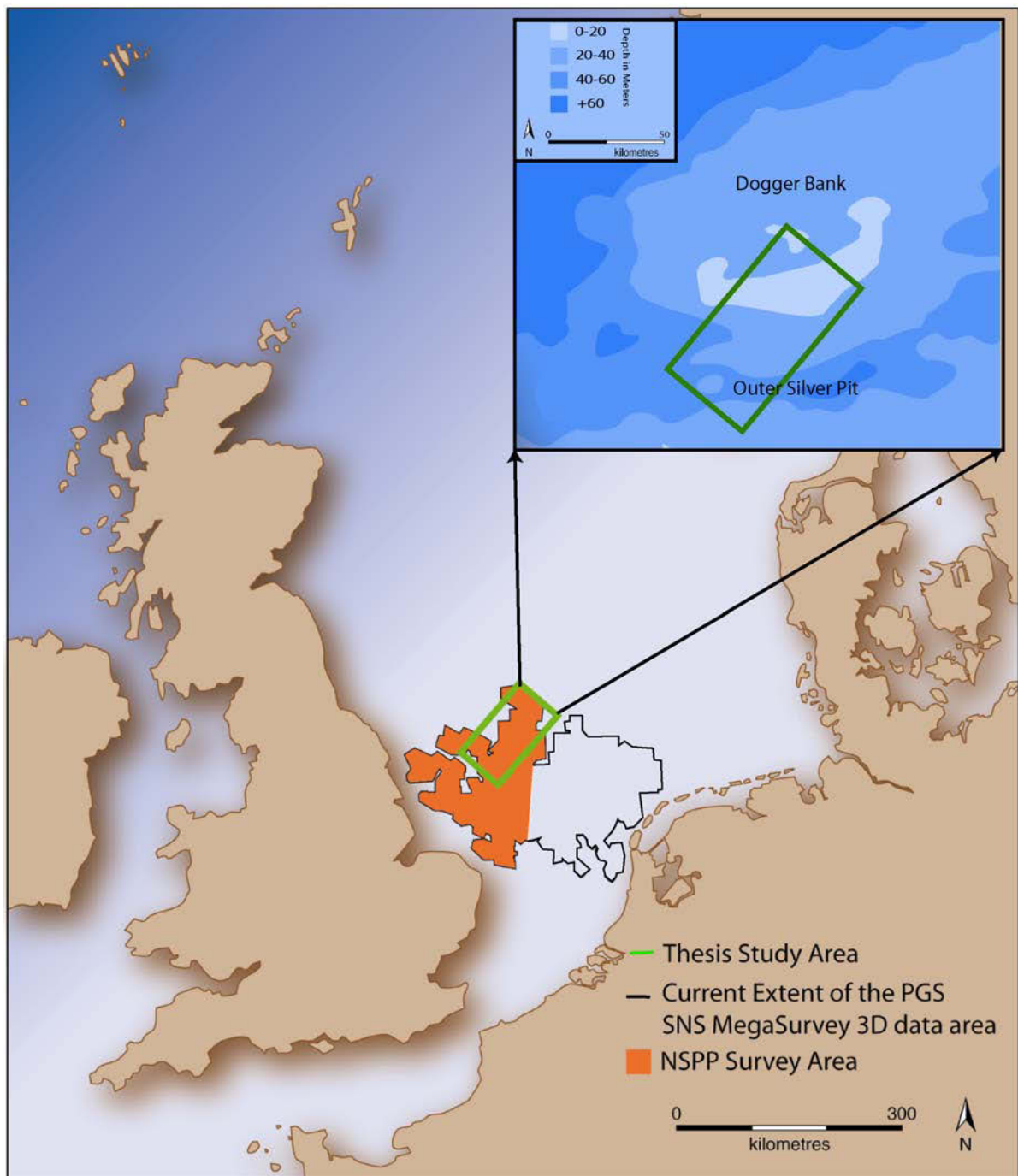
Figure 1.1 Location of the thesis study area in relation to the North Sea.

During halokinesis, low density salt moves up through the later denser rock units simply as an action of buoyancy (Brunstrom and Walmsley 1969). These salt structures have been active throughout the Pleistocene and Holocene, and in many parts of the southern North Sea they are still active today (Balson and Cameron 1985). The process can be seen to depress the Late Pleistocene sediments down by some 10's of meters, whilst raising them locally in others. The effects of this movement can be seen in the study area with a salt dome clearly visible as a small regional high within the Outer Silver Pit region (Figure 1.2). The effects of this on a landscape would have been to produce a series of regional "highs" (and "lows") throughout the area. Additionally, halokinetically induced faulting could also have displaced post glacial deposits (Novak and Bjorck 2002: 462). A more profound effect of this upwelling is the movement of Cretaceous chalk. This movement brought flints close to, or even up to the surface. Novak and Bjorck (2002: 462) observe that salt movement has brought chalk to within -50m of the surface of Denmark, and a similar observation can also be made in the south of the study area. The chalk here has been brought exceptionally close to the late Pleistocene/ Early Holocene land surface (see Figure 1.2).
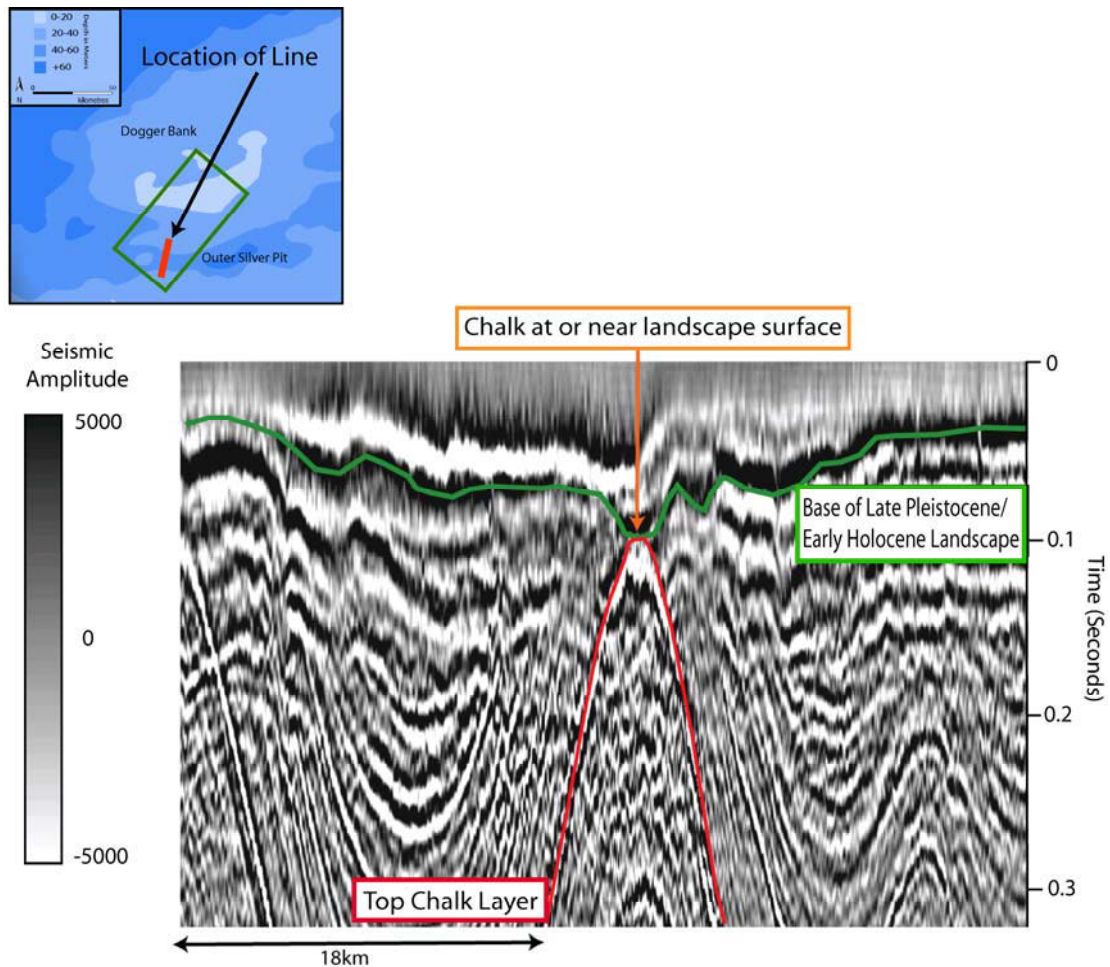
Figure 1.2 The proximity of chalk beds to the landscape surface in the study area as derived from the seismic data provided for this thesis.

The next rock units found overlying the Permian are those of Triassic age (250 to 210Ma), which contain fluvial sandstones, whose permeability has led to them being one of the main gas reservoirs within the region (e.g. the Forbes and Esmond gas fields). However, these deposits do not outcrop in the study area. The Jurassic (210 to 140 Ma) and Cretaceous (140 to 65Ma) rocks are also found within this region. These include a variety of different rocks such as limestone and mudstone, which would have been associated with a variety of similar archaeological landscapes as evidenced by their presence in the East Coast of the southern North Sea near Yorkshire. Later Cretaceous units that occur widely are

largely composed of marine mudstones and chalk, and these rocks also outcrop in the study area in the Outer Silver Pit region (and observed in association with halokinetic movements).

During the Tertiary (65Ma to 2.3Ma), seafloor spreading, caused by plate movements, was experienced in the North Sea basin. This movement generated widespread halokinesis and rock deformation. Following the Tertiary, later rocks of Pleistocene age were deposited. The Pleistocene can be seen to form the base of geological deposits in this region, and hence the building block of the later Holocene landscape. In this work, the start of the Pleistocene is taken as 2.3Ma (Gibbard *et al.* 1991) which is considered by Cameron *et al.* (1992) to be the best applicable start date for this region.

During the Pleistocene period the southern North Sea area was dominated by subsidence running parallel to the British coastline, with a northerly trend. This subsidence occurred at a rate of this approximately 0.5m per thousand years (Stoker *et al.* 1985). In addition to the geological movements generated by this subsidence, widespread salt movement also occurred within the study area throughout the Pleistocene. This produced a suite of halokinetic structures (including anticlines and synclines) as well as brittle faults such as the Dogger Fault Zone. These are suggested to have controlled sedimentation locally (Cameron *et al.* 1992). In the shallower section, primarily the Holocene and Pleistocene sediments, normal faulting is often associated with the crests of salt domes. Deeper fault zones are recorded within the region, such as the Dogger Fault Zone. However, these deeper faults have had little influence upon the more recent sediments within the region.

The lower Pleistocene can be observed to form a series of deltaic deposits. Long *et al.* (1988) observed these to be both thick and laterally extensive. The provision of sediment from the British Isles into this depositional system produced some restricted deposits in the region, but the overall deposition reflects the dominant European input of sediment into the southern North Sea during the Lower Pleistocene, which extended the Netherlands delta plain (Zagwijin, 1989). This massive input of material caused rapid sedimentation in the southern Blight, which conversely starved the north of the North Sea of sediment (Cameron *et al.* 1992).

The middle Pleistocene begins with the record of glacial ice entering the southern North Sea, with large "scaphiform" tunnel valleys being created at the base of these glaciers (Ehlers *et al.* 1984). These valleys are filled with glacial clay, which are then replaced by lacustrine and marine clays. The glacial material deposited in this region is thought to represent the Anglian glaciation (Gibbard *et al.* 1991). The ice of which eventually blocked the southern Bight and is thought to have diverted fluvial activity, as well as glacial melt water south through the English Channel (Gibbard *et al.* 1988, Hamblin *et al.* 1992). Eventually, this glacial period ended. The ensuing interglacial caused the retreat of the ice and the establishment of marine conditions in the southern North Sea. These interglacial conditions did not last however, and ice began to form in the Dutch sector of the North Sea (Joon *et al.* 1990). Subsequently, the British sector formed a periglacial area (Balson and Jeffery 1991).

Environmentally, the Late Pleistocene within the southern North Sea basin is characterised by changes between glacial and interglacial periods (Laraminie 1989b). The sedimentary record indicates several changes between glacial, terrestrial and marine environments. Eisma (1979) observes that this time period is the most important with respect to landscape morphology. The broad shape of the topography of the southern North Sea was created by the changing glacial processes throughout this period. The first stage in the Late Pleistocene history (often known as the Weichselian) is represented by the Bolders Bank formation. This deposit consists of the bulk of sub glacial sediments (Van der Meer and Laben 1990) in the form of stiff clays interspersed with pebbles and boulders of Cretaceous Chalk. The deposits on the Dogger Banks, the Dogger Bank formation, have much fewer and smaller clasts.

The end of the Weichselian can be observed within the sediments in the Botney Cut Formation. This formation fills glacial valleys within this area with glaciolacustrine and glaciomarine muds. The Botney Cut Formation signifies the end of the Pleistocene, and gives way to Holocene deposits. The Botney Cut formation does not fill all the Late Weichselian features; several of these scaphiform valleys remain partially filled within the landscape, even to this day. Whilst the terminal glacial deposits form the backbone of the geology within this region, later Holocene erosion and deposition has been significant. Holocene sediments attain a thickness of 1 to 5m within the region. Locally significant deposits can reach thicknesses of between 16 to 30m (Laraminie 1989a, Fitch *et al.* 2005). These Holocene deposits record the marine transgression of the emergent landscape of the southern North Sea.

West

Dogger Bank

East

seabed

20km

Holocene
Indefatigable Grounds Formation

Terschellingerbank Member

Western Mud Hole Member

Elbow Formation

Pleistocene
Botley Cut Formation

Well Ground Formation

Bolders Bank/Dogger Bank Formation
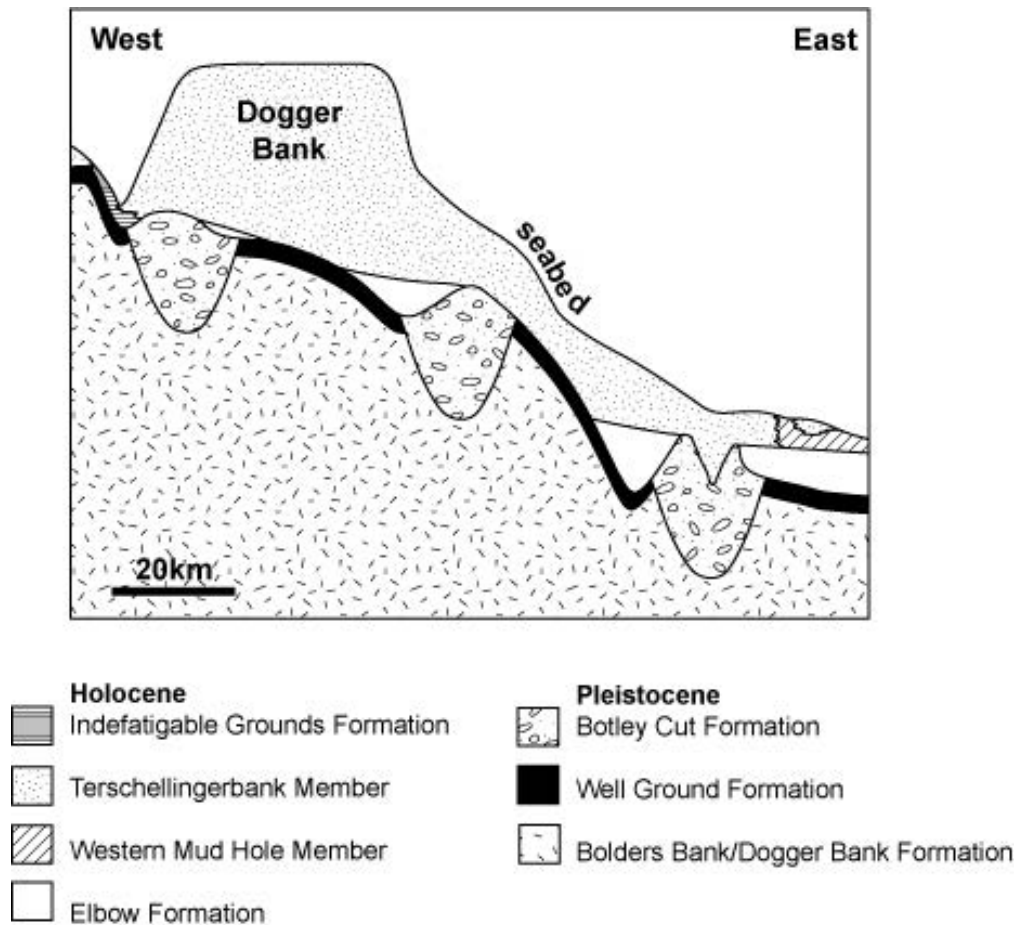
Figure 1.3 Geological cross section through the Pleistocene and Holocene geology of the study area (after Fitch *et al.* 2005).

The early Holocene Elbow Formation (Figure 1.3, 1.4) is of considerable significance to archaeology and consists of a basal clay layer and, locally, a basal peat. A number of peat samples have been recovered from the North Sea (see Ward *et al.* 2006 for a review) from this formation, most of which suggest that the Dogger Bank region was emergent at 9500BP (Behre and Menke 1979), but was experiencing fully marine conditions by approximately 7500BP (Jelgersma 1979). These deposits therefore are of prime importance, as they contain the environmental records for the period of time under study. The start of the marine transgression of the landscape is also recorded by the presence of brackish-marine

and tidal flat deposits (Oele, 1969). The overlying Terschellingerbank member and the

Indefatigable Grounds Formation (Figure 1.3) represent the products of more recent marine

processes and form a veneer over the area (Laraminie, 1989a).
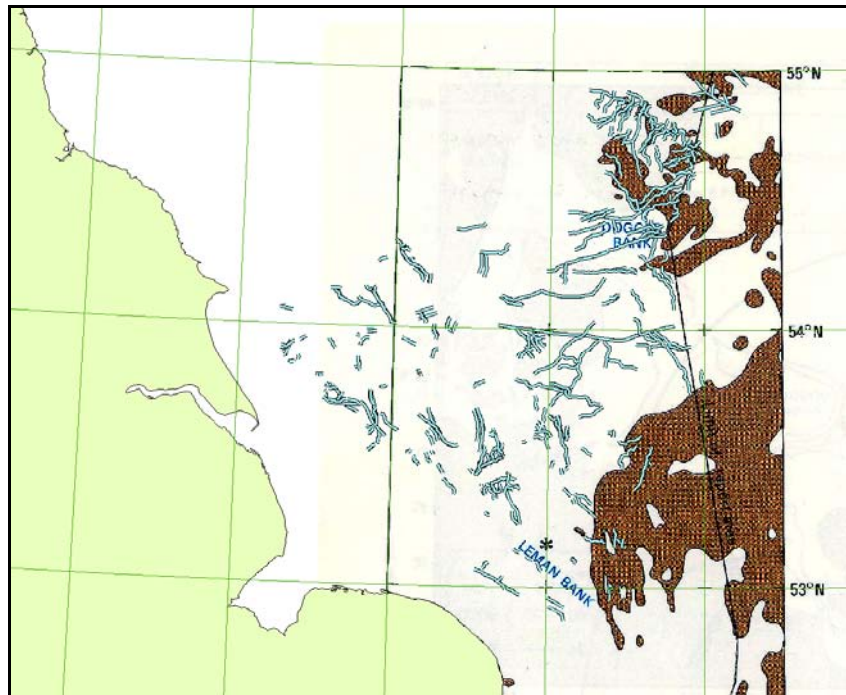
Figure 1.4 The distribution of the Elbow Formation in UK waters (shown in brown) from
Cameron *et al.* 1992. Rivers Identified by the NSPP are shown as blue lines.

The geology of the area has helped shape this landscape, however, it is the effects of the

last glaciation, and the later marine erosion, that have formed the surface that can be

observed today. It is also apparent from the Quaternary record that extensive Holocene

deposits are present in the southern North Sea, but that much of this material is covered by

recent sands (1 to 25 metres of material). Given this coverage of recent material, it is

perhaps not surprising that the Holocene landscape has been obscured from traditional

archaeological survey methods.

1.4   Evolution of the Holocene landscape: Sea level change

One of the most enduring components of the evolution of the Holocene landscape is the ongoing process of sea level rise throughout this period. Fundamentally, this controls not only the physical features, such as the base level of fluvial systems, and the location of coastlines but, at a human level, deprives access to pre-existing resources, or provides new opportunities within the landscape. The Holocene sediments in this area record the environmental change which occurred during the inundation. These changes would have been, at times, spectacular (Kooijmans *et al.* 2005), and would have been spatially significant in the lowland locations of the southern North Sea (Shennan 1989, Lambeck 1991).

Sea-level observed at any location, is composed of two main components; that of eustatic and relative sea level change. The eustatic component refers to the changes in the global water supply, through the addition or subtraction of water from the global oceans through the formation/melting of ice sheets. Relative changes in sea-level are more localised and refer to the changes in sea-level at a given area or point on the coastline. Obviously therefore, these changes are a composite of a variety of factors (Morner 1976), consisting of crustal movements, eustasy, sedimentation and sediment compaction, all of which have significant effects upon the relative topography of the landscape.

For site based reconstructions of palaeo-sea level, the most common technique is through the utilisation of SLIPs (Sea-level Index Points). Whilst it is not in the scope of this thesis to discuss these in detail, it is important to provide a background into which the

palaeolandscape can be placed. SLIPs are a stratigraphic analysis of specific deposits and sedimentary relationships, such as a peat-clay boundary to produce an understanding of the prevailing palaeo sea-level of a localised region or site (Shennan *et al.* 2000).

The basic definition is provided in Shennan (1986). In this seminal paper the "rules" for the use and definition of a SLIP are provided. The paper not only provides the indicative meaning of SLIPs, but also the relationship to the height of tidal sea level at that period. Whilst SLIPs represent "real" data on sea level and are helpful in understanding past sea level change, their use is complicated by issues such as palaeotidal range (Shennan 1986, 156 -157), environmental conditions as well as peat autocompaction (see Allen 2000 for a good discussion of this). All of these factors are considered to place limitations on the accuracy of the modelled data (Shennan 1986). Despite this, SLIPs provide highly accurate information for localised areas, which are invaluable to archaeological studies at a similar scale (e.g. Bell 2000). Other work with SLIPs in relation to bio-environmental indicators is showing promise in improving the input data (Zong and Horton, 1999).

However, individual SLIPs offer little information of sea level on the continental scale. Additionally, they are unable to proffer any information on marine areas (such as the North Sea), where information on such index points is sparse. One of the earliest attempts to resolve this situation through the use of multiple SLIPs and sea level curves was produced by Jelgersma (1979). This is perhaps the most referenced piece of work and the most influential on archaeological interpretation of the North Sea region (Coles 1998). Through the use of the available bathymetry data, in combination with recent sea level curves,

Jelgerma was able to produce a set of hypothetical coastlines for the period 18,000BP to 7,800BP. Jelgerma also utilised the constraint of known locations of peat samples in the marine sphere and index points on land to further improve the model.

The resulting "maps" of the coastline appear to be convincing, and many workers in this field have referred to these diagrams. This is due to the fact that they produce a clear map of the emergent plain (e.g. Cameron *et al.* 1992, Verhart 1995). Whilst these diagrams lack any landscape features, they provide a method by which a consideration of the sea level in relation to the emergent landscape can be attempted. However, there are fundamental issues in the undertaking of such a reconstruction. The most critical of these is the use of the modern bathymetry as an analogue for the palaeolandscape. This use ignores burial and erosion processes that have modified the landscape, in some cases in the order of up to a few tens of metres vertically (Cameron *et al.* 1992, Fitch *et al.* 2005). This represents a potential error that is introduced into these reconstructions. Considering the low lying nature of the landscape (Coles 1998), such an error suggests that most palaeocoastlines are unlikely to be in the position indicated by the model. Other potential sources of error exist within this model. These factors include tectonic influences and isostatic rebound, neither of which are considered in the model.

To address some of these issues, the Glacio-Isostatic Adjustment (GIA) model was generated utilising isostatic rebound models in conjunction with multiple SLIPs. This sought to provide a model of the temporal and spatial changes over larger landscapes, which addressed some of the issues with Jelgersma's model. Early representations of such models

were limited by computing power and available large scale datasets (Peltier 1994).

However, improvements in both datasets and computational capacity allowed Lambeck

(1995) to improve on previous models. Whilst his work produces clear coastlines, the use

of more comprehensive data also allowed him to model the relative heights of the

landmass through the Holocene and the effect of relative sea level rise. This, therefore,

provided a basic outline of the landmass with relative highs and lows mapped on the

landscape along with the coastline.

Even with this improvement, Lambeck (1995) does acknowledge errors in this method and

the problems of resolution, some of which were addressed through the inclusion of new

core data (Lambeck 1998). Lambeck (1995) himself observed that the model still presented

problems related to ice which was "missing". Indeed these assumptions have been an issue

throughout GIA research, resulting in possible underestimates of relative sea levels in the

southern North Sea (Shennan 2002, 513). Improvements to the Glacio-Hydro-Isostatic

Rebound models, produced by Shennan *et al.* (2000), in collaboration with Lambeck,

improved analysis and provides impressive imagery of the landscape (see Figure 1.5).

However, it is important to note that this is still based on satellite bathymetry (Shennan

2000), and thus suffers similar issues to that of the model produced by Lambeck in 1995. It

also remains susceptible to similar erosional/depositional issues that are associated with

Jelgersma's (1979) model. This is acknowledged as a significant error in the assumptions of

the GIA model, with Shennan stating "At the present stage in the analysis we ignore

sediment erosion and deposition" (Shennan 2003, 308). Further improvements in such

models have yet to correct for this (e.g Shennan 2003, Peltier 2005). Shennan (2003, 308)

also points out another major problem that has dogged many workers in this field, that "there is little justification in increasing the sophistication of models if there is no data to test their output". Thus, the lack of data and poor resolution (especially for bathymetry) has hindered improvements to this modelling strategy.
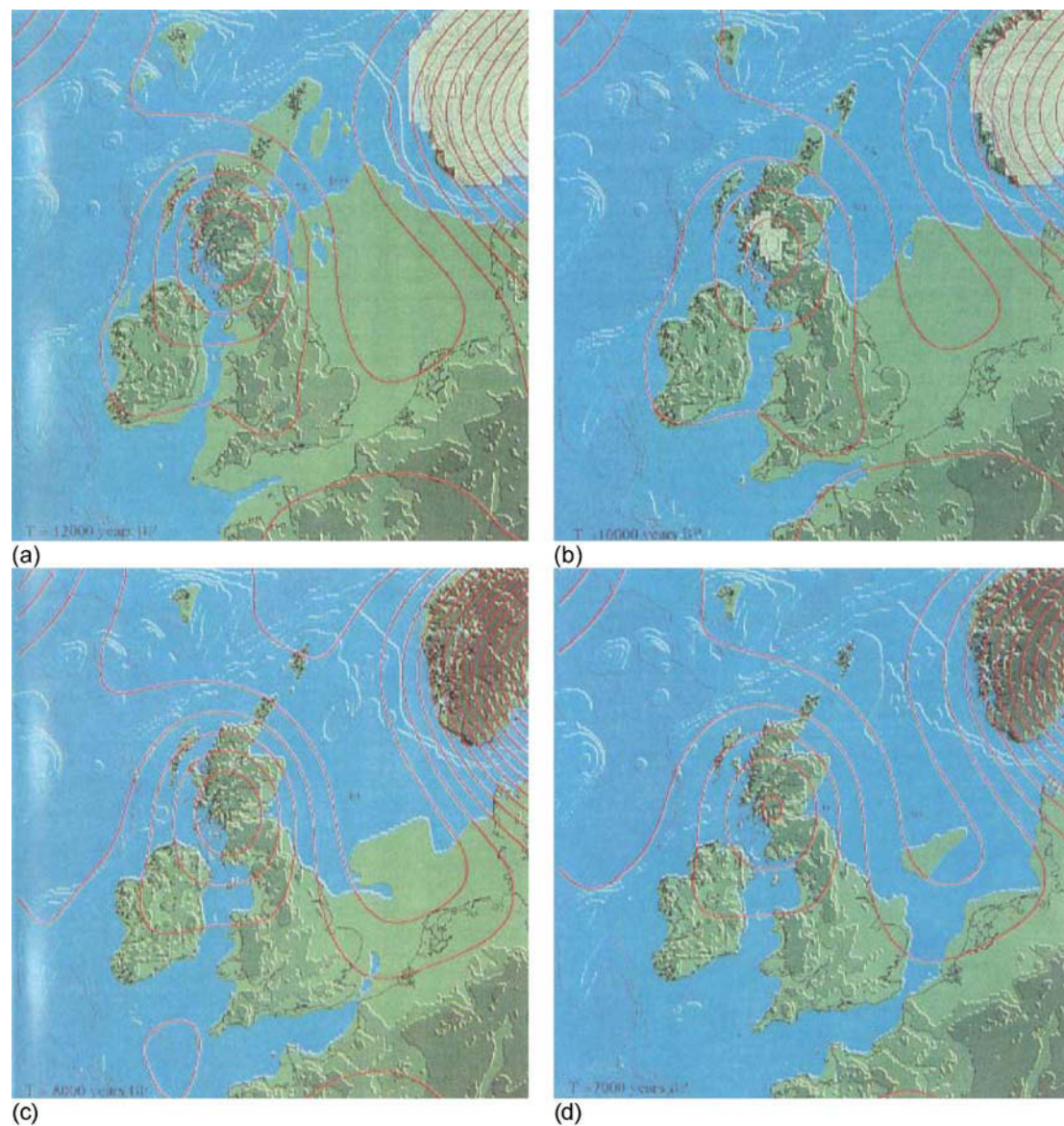
Figure 1.5 Shennan's (2000) models of the landscape of the southern North Sea for: a) 12,000BP, b) 10,000BP, c) 8,000BP and d) 7,000BP. Note: Figure quality is a product of the original illustration.

1   Shetlands
2   Orkney
3   Wick
4   Dornoch Firth
5   Moray Firth
6   NW Scotland (Coigach)
7   Hebrides
8   Skye
9   NW Scotland (Applecross)
10 NW Scotland (Kintail)
11 NW Scotland (Arisaig)
12 NW Scotland (Kentra)
13 NE Scotland
14 Aberdeen
15 Montrose
16 Tay Valley
17 Forth Valley
18 Islay
19 Ardyne
20 Clyde
21 Ayr
22 SE Scotland
23 NE England (North)
24 NE England (Central)
25 NE England (South)
26 Tees
27 N Solway Firth
28 S Solway Firth
29 Cumbria
30 Isle of Man
31 Morecambe Bay
32 Lancashire
33 Mersey
34 N Wales
35 Mid Wales
36 Humber (Inner Estuary)
37 Humber (Outer Estuary)
38 Lincolnshire Marshes

39 Fenland
40 Norfolk
41 East Anglia
42 S Wales (Pembrokeshire)
43 S Wales (Glamorgan)
44 Bristol Channel
45 Essex

46 Thames
47 Kent
48 Sussex
49 Hampshire
50 SW England (Dorset)
51 SW England (Devon)
52 SW England (Cornwall)
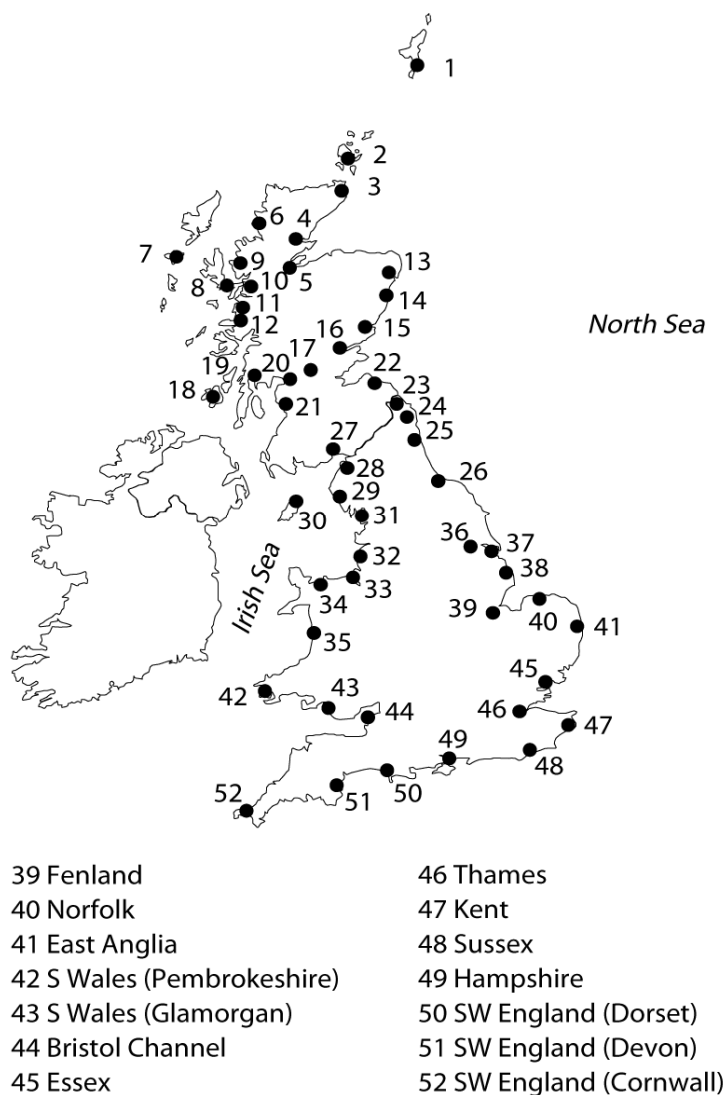
Figure 1.6 Location map of the 52 sites utilised by Shennan (from Shennan *et al.* 2002).

Unfortunately, other issues are associated with these Isostatic models, but Lambeck (2001) defends the formula produced in Shennan (2000) as sound, and importantly observes that any defect in the model must lie in the input. This point is accepted, but there are other important factors to consider with this model. Initially, it must be observed that almost all of the sea level index points utilised by Shennan in 2000, and his later work in 2002, are onshore or nearshore (see Figure 1.6). Only a small number of locations in the far offshore are utilised within the model. This, therefore, constrains the accuracy of this model, especially for the offshore southern North Sea area. In addition, Peltier (2004, 126) challenges the older ice and lithospheric models utilised by Shennan (2000) and observes the differences presented by newer data. Peltier notes that the lithospheric thickness of 120km, used previously by Shennan, should perhaps actually only be 90km (Peltier 2004, 126); a modification which Peltier (2004: 126) states "fits all of the GIA data from the British Isles extremely well". Despite these issues, the influence of Shennan's (2000) maps on archaeology has been significant. Most archaeologists could be forgiven for regarding it as the accepted model for the landscape in the region, but, there is some confusion by the archaeologists as to what the models represent (Coles 1998), and a lack of understanding of the underlying assumptions and calculations associated with such models (Bell *et al.* 2006, 14). The scales at which these models operate also make them unsuitable for the purposes of archaeological interpretation (e.g. Shennan 2000, Pelitier 2005). Even when considering higher resolution local models, the utilised cell size of 1.2km x 1.2km (Shennan 2002: 513), is still extremely large.

Whilst Shennan's work has proved a useful lead to improve archaeological awareness, these models are too often mistaken for representing a "real" situation in archaeology (e.g. Pryor 2004). To rectify this situation, there is a need for the provision of additional survey in the region. This would provide information not only on the actual real world locations of past coastlines and landscape features, but also information that could be integrated into improved future iterations of GIA models. This could be achieved through the targeting of locations to provide future SLIPs for the southern North Sea. It would also serve as a series of spatial constrains, which could be incorporated within the model. The provision of adequate information would go some way to resolving Shennan's (2003) issue with future GIA modelling. The mapping of the archaeological landscape offers a way by which such models could be tested.

Given the issues associated with sea level research, bathymetry and landscape reconstruction, it is readily apparent that the utilisation of the results of such work for an archaeological landscape exploration is unrealistic. There is a need for recourse to other methods which overcome these issues. The use of 3D seismic data is one such avenue that facilitates the actual recording of the landscape in a less speculative manner.

1.5   A very brief vegetation history of the study area

Pollen analysis over a period of nearly 80 years in the British Isles has facilitated the reconstruction of a fairly consistent picture of environment change in the UK during the period after the end of the Ice Age. Unfortunately, the local picture for the southern North Sea is less complete. Normally, pollen analysis of terrestrial sediment is fairly straightforward. However, the complications, in both technical and in funding terms, result from the need to collect material from below several 10s of metres of seawater, which is costly and time consuming. As such these restrictions have served to limit the amount of material available for analysis in the southern North Sea region. Despite this, there have been attempts to look at pollen from various blocks of material from the bed of the North Sea, retrieved in fishing nets or by dredging. The earliest study of this data was performed by Godwin (1943, 1945), who examined 'peats' from samples taken in the north of the region. However, the spatial extent of this work is limited. Without material suitable for analysis from areas such as the Outer Silver Pit, definitive information on the local conditions remain speculative and is based on our understanding of general trends in vegetation change. Pollen Isochron maps, such as those produced by Huntley and Birks (1983 - Figure 1.7), can be used to guide the understanding of these trends. The general trends are reasonably clear. Early Late Glacial tundra, is replaced by sporadic scrubby birch and willow forest as temperatures began to rise. Low-lying areas next to rivers were covered in wetland marsh vegetation such as sedge and reeds. After 11,500 BC birch woodland appeared, with some willow and hazel predominating at first; with pine becoming dominant later in the period. By 9,500 BC much of the area is either under mixed conifer and deciduous forest, or under dense mixed deciduous woodland. The latter mainly

comprised of hazel, oak and elm at the start of the period, rapidly joined by alder between

8-7,000 BC, ash at around 6,000 BC) and lime at around 5,500 BC.

From the available evidence, it is difficult to determine the actual rates of woodland

sequence development, nor the specific form of woodland present. This is primarily due to

the lack of reliable pollen samples from the study area. This provides further complexity as

Birks (1989), for example, suggests that several species of tree arrive in Britain via

Doggerland. Further complexity could be added, as the woodland cover of Doggerland

must have responded to rising sea levels and salt ingression through the process of forest

die back.

1 Tundra; 2 Birch forest; 2a Birch forest: *Populus* variant; 3 Birch-conifer forest; 4 Spruce-dominated forest; 5 Northern mixed conifer-deciduous forest; 5a northern mixed conifer-deciduous forest: *Pinus* variant; 6 Mixed deciduous forest; 7 Montane mixed conifer-deciduous forest; 8 Montane mixed-conifer forest; 8a Montane mixed conifer forest: *Pinus* (Haploxylon)-*Larix* variant; 9 Mediterranean forest; 11 Steppe; 11a Steppe: treeless variant; 12 Grassland; 13 Mixed forest.

Figure 1.7 Isopollen maps showing changes in vegetation over the post glacial (adapted from Huntley and Birks 1983). The poor reproduction here is a product of the original diagram.

1.6 Archaeological record from the immediate study area

Very little archaeological material has been recovered with respect to the Mesolithic archaeology of the study area. However, Clark in "*The Mesolithic Settlement of Northern Europe*" records findspots of moorlog from the study area (Clark 1936, see Figure 1.8.). No actual archaeological finds have been reported[1] from the study area. This is unsurprising given the absence of archaeological survey within the region and the submerged nature of the landscape.

The nearest recorded archaeological find is that of the Leman and Ower point (see Figure 1.8 for location.). Recovered from a block of moorlog in 1931 by the trawler Colinda's skipper, Pilgrim E. Lockwood, this artefact measures 8.5 inches in length (21.6cm) and features a row of barbs running along much of its length. This antler point probably formed part of a fishing leister, and is not unique in the archaeological record, rather, it has parallels in both Britain and Denmark. The radiocarbon date of 11740 ± 150 BP falls outside that which is generally accepted for the Mesolithic, and there have been several suggestions that the date may not be reliable. This unreliability may relate to the material either being reworked or that there is some error in the dating (Ward *et al.* 2006). Irrespective of this, the presence of this artefact in the area, which correlates to similar finds around the North Sea basin, indicates a human occupation within the study area at this period.

---

[1] Coles (1999, 57) quotes personal communication from Andersen for "an antler or bone artefact trawled from Doggerbank" which was radiocarbon dated to c. 6050 cal.BC. No other reference/report, radiocarbon lab code or location information of this artefact can found in the literature. It is therefore impossible to determine the accuracy of this report, nor if the find actually originates from the study area.
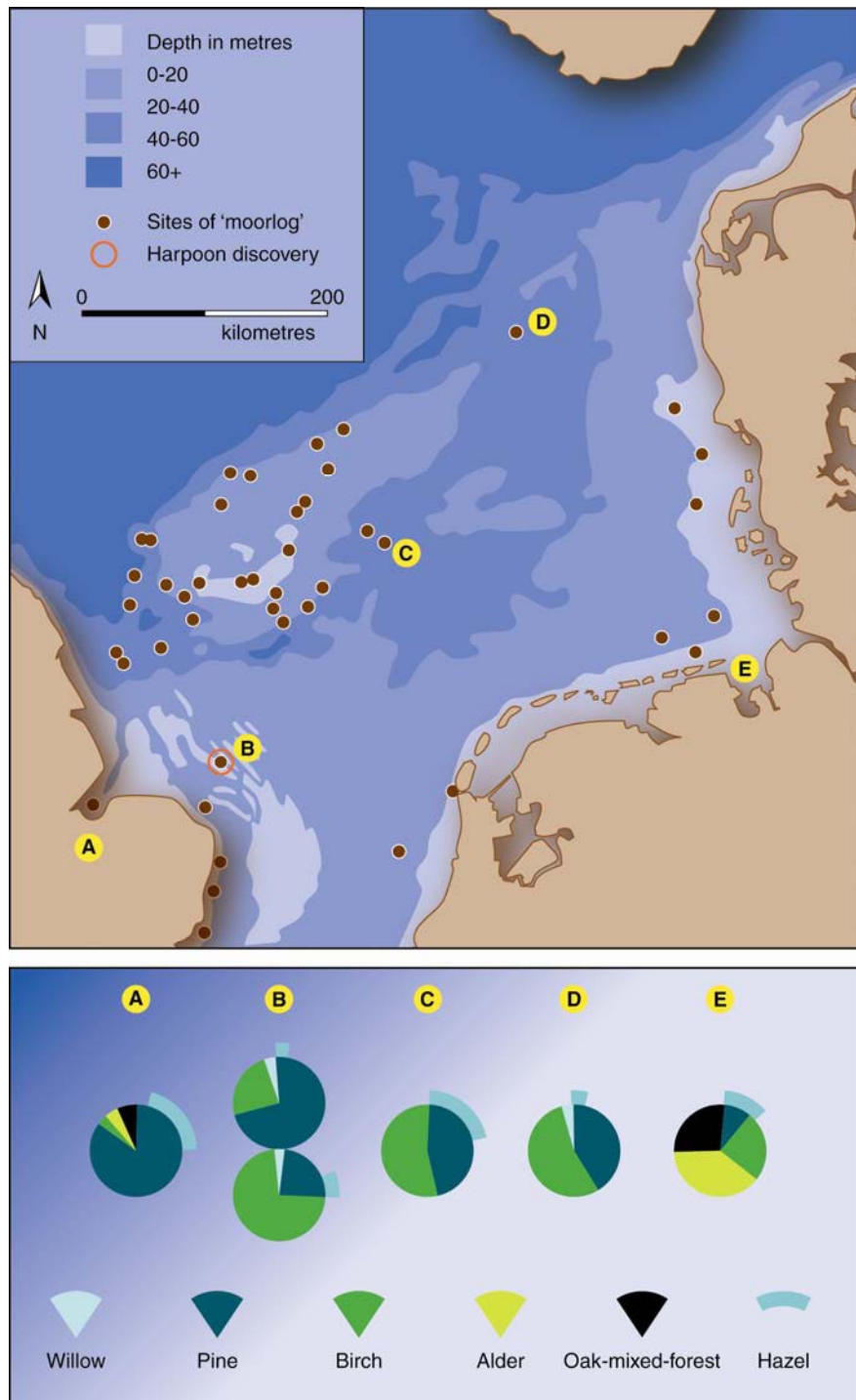
Figure 1.8 Findspots of moorlog and pollen spectra of samples from the North Sea. This is based upon Figure 3 in "The Mesolithic Settlement of Northern Europe" by Graham Clark (1936). Location 'B' is the site of the Leman and Ower point. The two pollen diagrams for location 'B' are due to two samples being taken from this point. This variation is likely to be due to the two cores sampling peats of different ages.

1.7   Outline of thesis and Chapter Summary

This thesis will present a model of the Mesolithic population in the southern North Sea in a manner that will add significantly to the current debate on the occupation of Mesolithic North Western Europe. It is important to stress that this is the first time such information has been realised for this region and, as such, has great potential to inform our understanding of the period and region.

In this chapter the study area has been outlined, and the nature of previous studies within the area investigated. The issues associated with study in a marine area have been outlined. These have been focused upon the scarcity of information available for study. The need for the provision of archaeological information for this area has been demonstrated. In the light of this situation, a suitable approach utilising 3D seismic information has been suggested. This application, it is suggested, will provide sufficient information to facilitate the modelling of human subsistence and occupation within the study area. In the following chapter (Chapter 2) the issues associated with the study of the Mesolithic in this region will be presented. As part of this the problems associated with the previous understanding of the Mesolithic landscape and its associated resources will be presented. After a discussion of the nature of archaeological evidence available to assist this study, insight will be sought on this "missing" heartland of Mesolithic Europe.

Chapter 3 will comprise of a discussion of the methodology undertaken to provide the required base datasets. The chapter will initially look at the use of seismic methods to build the topographic model. It will then proceed to look at the methodology for the generation

of the soil layer and the associated environmental information. In Chapter 4, the datasets

generated from the preceding methodology will be utilised within a general model. The

model methodology will allow the determination of human resource subsistence within the

region. To assist in the analysis of this information, a further methodology will be provided

for predictive modelling and catchment analysis. It is proposed that this will facilitate a

greater understanding of the dataset.

In the results (Chapter 5), the outputs of the methodologies presented in Chapters 3 and 4

will be considered. Drawing from this, the impact of the early Mesolithic coastlines upon

the subsistence and population of the region will be investigated. Through the use of

information derived from the basic site catchment analysis, insight into more localised

changes will be revealed. In light of the findings, it will be proposed that the old ideas of a

unified early Mesolithic culture may, in the future, require revision to include a much

greater impact of the coastline on Mesolithic society than previously expected.

In Chapter 6 the results will be discussed in more detail. It will be argued that the provision

of data has significance, as it supports an assessment of the impact of the flooding of the

North Sea upon hunter gatherer societies. Through this, it will be possible to observe

cultural responses. It will be argued that these responses affected lifestyle and decision

making to an extent that these groups may have considered themselves culturally distinct.

The final chapter will provide a summary of the results and discuss the idea that the data

modelled forms a unique dataset. Comments on the approach undertaken will also be

provided. In particular, future areas for improvement of the methodology will be

highlighted. The final sections will discuss the research legacy and its future implications,

and the application of such work in new research areas across the globe.

CHAPTER 2

REVIEW OF PREVIOUS RESEARCH

2.1   Introduction

The purpose of this chapter is to examine the issues associated with the study of the Mesolithic, with respect to the southern North Sea region. The Mesolithic record of this region is characterised by several key issues. These are the impoverished nature of the archaeological record, the difficulty of exploration and the terrestrial bias of current research. All of these issues primarily derive from the region's marine nature. As observed in the previous chapter (1.1), most of the available archaeological evidence can be considered as comprising of little more than stray finds (Kooijamans 1970). In addition the available environmental evidence, which is provided by geological mapping and core sampling for this region, is widely spaced (Gaffney *et al.* 2007). This information is often not suitable, as it is targeted for geological rather than archaeological purposes (Gaffney *et al.* 2007). Thus, the conditions are created where a reliance on information from the terrestrial zone is required to fill in the gaps presented by the marine data. The assertion of the North Sea as an optimal area for habitation by some researchers (Clark 1936, Morrison 1980) suggests that this may not be suitable. By exploring these topics, it will become possible to understand the importance of the Southern North Sea with respect to the Mesolithic, and the limitations of the archaeological record and landscape associated with the period.

2.2 Discussion – The archaeological perception of the emergent landscape of the southern North Sea through an examination of its mapping.

The perception of the southern North Sea as a Mesolithic landscape can, perhaps, be best explored through an examination of the past attempts to map it. Early attempts at the reconstruction of a landscape in the North Sea date back as far as the early 20th century. However, it is only since 1913 that the possibility of an emergent landscape in the southern North Sea became apparent to archaeologists.

Arguably, the first important map of this landscape is provided by Reid in his 1913 book "Submerged Forests" (see Figure 2.1). This early representation of the landscape after the last glaciation represents a culmination of information gathered by Reid in his investigation of the nature of submerged forests around Britain.

Reid, in his work, gathers a variety of information derived from coastal material and seabed recoveries of finds and wide ranging (for the period) palaeoenvironmental material. This use of environmental material to inform the interpretation of the landscape sets Reid apart from his contemporaries. Indeed, many subsequent archaeologists have failed to achieve this level of data integration. Reid must also be credited with, probably, one of most innovative maps of region, certainly until the 1990s. When Coles published her seminal synthesis on the region in 1998, she chose the name Doggerland to honour Reid's map and his early recognition of the area as a significant archaeological landscape (Coles 1998: 47).

Reid's early appreciation of the landscape must be noted. His willingness to include

hypothetical river systems to promote the idea of a landscape suitable for population is a

concept that few followed until Coles (1998) (e.g. Clark 1936, Jacobi 1976). Certainly, as

Coles (1998) observes, Reid is indeed one of the few early authors to understand that the

Doggerbank may well have formed a long lived island that persisted long after the

landscape links between Britain and the Continent had been severed. Thus Reid rightly

deserves recognition as one of the earliest authorities on this landscape.
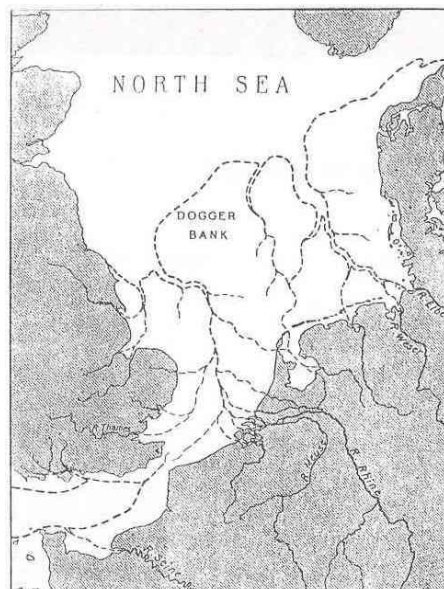
Figure 2.1 Hypothetical landscape of the southern North Sea produced by Reid (1913).

Unfortunately, Reid's work attracted little attention. However, the issues of mapping the

North Sea landscape attracted the attention of one of the best known names in Mesolithic

archaeology, Grahame Clark. The influences of Clark's earliest map of the region (Figure

2.2), in "Mesolithic" (1936) may well owe its origin purely to the discovery of the Colinda

point in 1931. Fagan (2001: 41) states that it is the discovery of this point that was

fundamental in developing his appreciation of an inhabited North Sea landscape. The

effect of this is important, as it is this realisation that is reflected in his map of the region

(see Figure 2.2). This knowledge led Clark to suggest suggesting that the Doggerbank region

may have been the "heartland" of the Mesolithic. However, the 1936 map also represents

archaeological thinking at the time, with his placement of the Leman and Ower point in

relation to British and European points. This, perhaps, suggests that Clark was seeking to

link the British and European Mesolithic records closer together. This idea, is also

suggested by Clark's biographer, who purports that Clark's thesis for the area was that

Britain was colonised from Europe across the North Sea (Fagan 2001: 41).

Coles (1998: 48) highlighted Clark's map for its illustration of lakes near the Outer Silver pit

area. However, caution must be applied, as these lake "features" illustrate that Clark, was

simply adhering to the bathymetric contours of the region. This may suggest that Clark

misunderstood the nature of bathymetric data, to the point of having to draw lakes in the

bathymetric depressions. However, given the lack of available data, the absence of rivers

continuing from the modern coastline on the map is a wise move (Coles 1998: 48). Clark's

later works show the limitations of the lack of new data available on this area, with little

development from his earlier maps (e.g. Clark 1975).

Fagan (2001) suggests that the lack of new evidence appears to have led Clark to the point

where he appears to have dropped the vision of the landscape. Coles (1998: 48) also

suggests a possible change in Clark's ideas from a preferential landscape to a more

conventional (for the time) land bridge idea. However, this change in ideas is unlikely, due

to his continued observance of this region as focus for Mesolithic occupation (Clark 1980, 41). Rather, it is more plausible that, with the lack of new mapping evidence available, Clark felt unable to improve on his previous ideas.
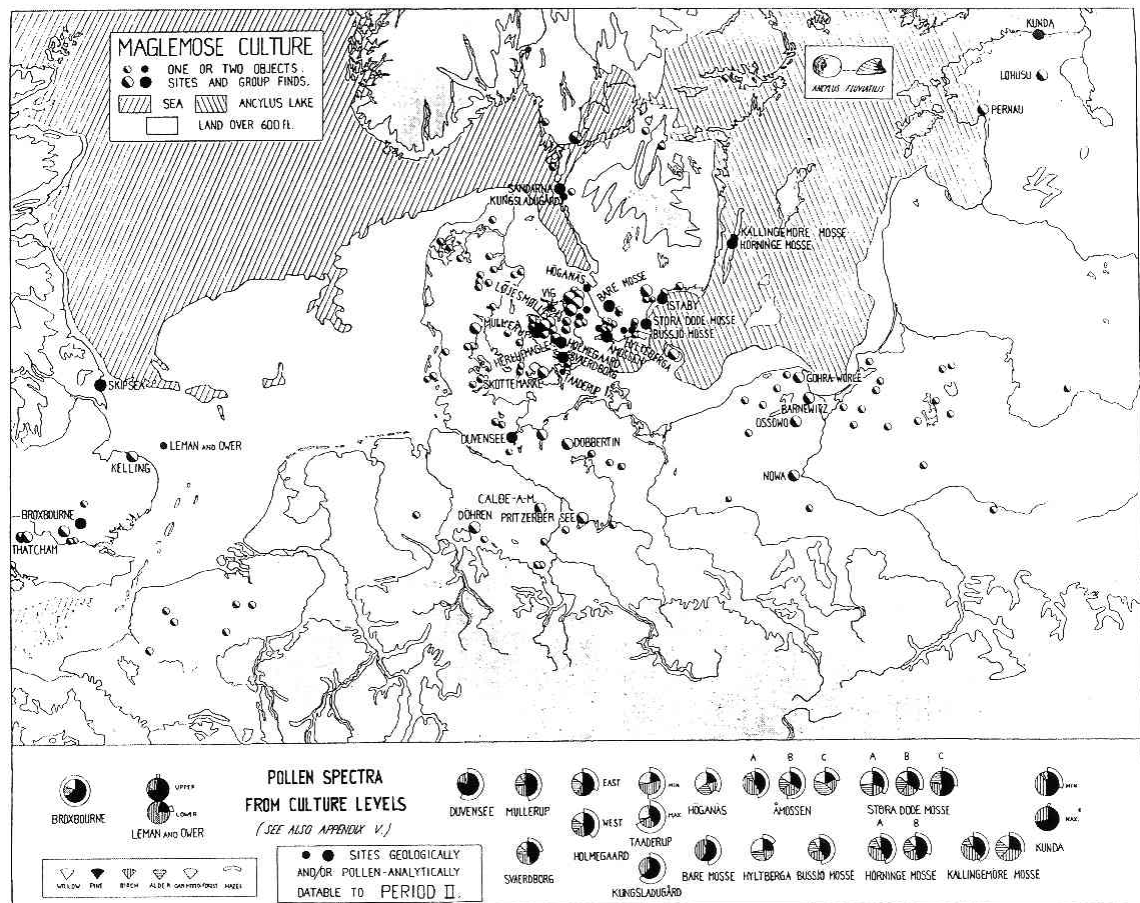
Figure 2.2 Clark's map of the Mesolithic landscape of the southern North Sea (from *The Mesolithic Settlement of Northern Europe*, 1936).

The absence of focused research in the area can be clearly discerned in the literature following Clark. The North Sea region was marginalised and largely forgotten during this period, to the point that when the next map of this landscape appeared, Jacobi (1976) had largely devolved the discussion of the landscape into its role in connecting Britain and

Europe into one single cultural zone (Figure 2.3). Interestingly, it can be observed that Jacobi's maps do not even include the location of the Leman and Ower point. Furthermore, his scepticism concerning the nature of the landscape is such that the bathymetric "coastlines" are smoothed and idealised. The concept provided by Jacobi's map is that landscape is of little interest to archaeologists, with more interesting things occurring on both sides, and the North Sea being clearly represented as a blank canvas. Jacobi's reconstruction of the landscape, therefore, is the epitome of the fate of the emergent landscape for the period from 1936 to 1992, with its relevance to Mesolithic archaeology related to a washed out, shadowy link between Britain and the Continent.

Figure 2.3 The emergent landscape of the southern North Sea, (Jacobi 1976).

Figure 6.1: Map of the North Sea area during the eighth millennium bc. The possible coastline is suggested by the present 20-fathom (−37 metre) contour.
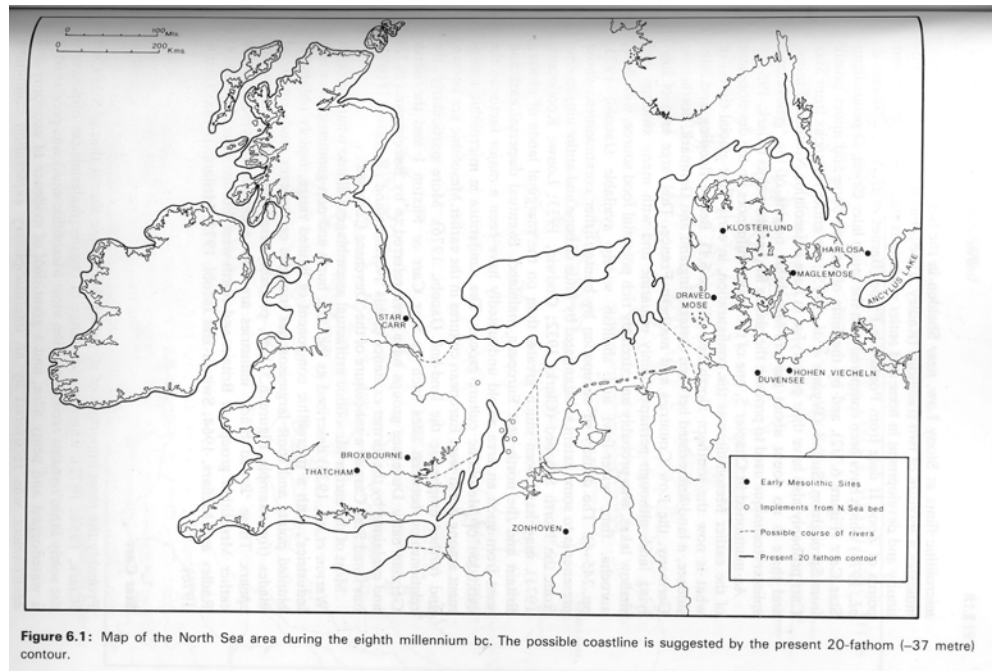
Figure 2.4 The emergent landscape of the North Sea, as portrayed by Morrison (1980, 117).

Morrison's 1980 map of the landscape (Figure 2.4), can be seen as an attempt to revive the idea of the North Sea as an area of "rich potential" for hunter gather societies (Morrison 1980: 118). Morrison's work is often overlooked, Coles (1998) observes that "Morrison at times sounds dubious about any Holocene landbridge (1980: 102)", however, this is a misinterpretation of Morrison's work. Morrison is rightly cautious, observing that there are difficulties in proving the existence of the land links through the lack of direct evidence. He does observe that the southern North Sea must have been connected to the continent ,and that the presence of the Leman and Ower point supports this view (1980: 102). His map clearly shows some appreciation of the landscape, even to the point of suggesting river courses, which few of predecessors, let alone contemporaries, attempt (1980: 117). His map also benefits through the inclusion of both the present and past coastlines of the area. His further inclusion of the location of Early Mesolithic sites (1980: 119) provides a map that

41

rivals more recent authors' (c.f. McFayden 2006), and attempts to place sites within their landscape. It must be noted, however, that though his maps are laudable, they lack substantive landscape information due to a lack of suitable data.

If Morrison's work is examined in depth it is clear he was committed to the principle of the North Sea as a centre of Mesolithic culture, and his emphasis on this region becomes apparent. Morrison emphasises the extremely rich food resource available, highlighted through the dredged bone evidence. This line of enquiry eventually leads him to the suggestion that the density of occupation in the North Sea region may have been much more than the marginal lands of Britain and the north-western European mainland (1980: 118). Clearly, Morrison understood the potential for occupation of the southern North Sea area. Indeed, Morrison's work is best regarded as a missed opportunity to inform and stimulate a new generation of archaeologists to provide details of the archaeological landscape, and so his map had little impact. Jensen's synthesis of *The Prehistory of Denmark* (1982) notes the existence of the North Sea emergent plain, but ignores Morrison's work, and the North Sea is, once again, relegated to the position of a landbridge (Jensen 1982: 16.)

Perhaps the most notable advance in the understanding of the landscape for this period is by Smith (1992). This work represents a quantum change in the direction from which the landscape would be envisaged. No longer relying on a few "loose" finds to inform investigation into the landscape and its inhabitants, Smith utilises the available

palaeoenvironmental data to allow the investigation of the landscape as a habitable environment, rather than a simple coastline.

It is obvious from the maps produced by Smith (see Figure 2.5) that he made no attempt to utilise the information made available from the prevailing isostatic models of the day, including Jelgersma (1979). Coastline accuracy suffers because of this, but his map's content and message suffer little. Indeed, the mapping of plant distributions are shown across the whole of the North Sea emergent plain, and his distribution map of settlement sites (1992: 166) follows a similar pattern. This was revolutionary when compared to past efforts (cf. Morrison 1980, Clark 1936, cf. Coles 1998), which fail to reproduce this level of landscape information.

Figure 2.5 Smith's (1992) mapping of landscape evolution and plant distributions across the southern North Sea. (Note: Poor reproduction is a product of the original figure).
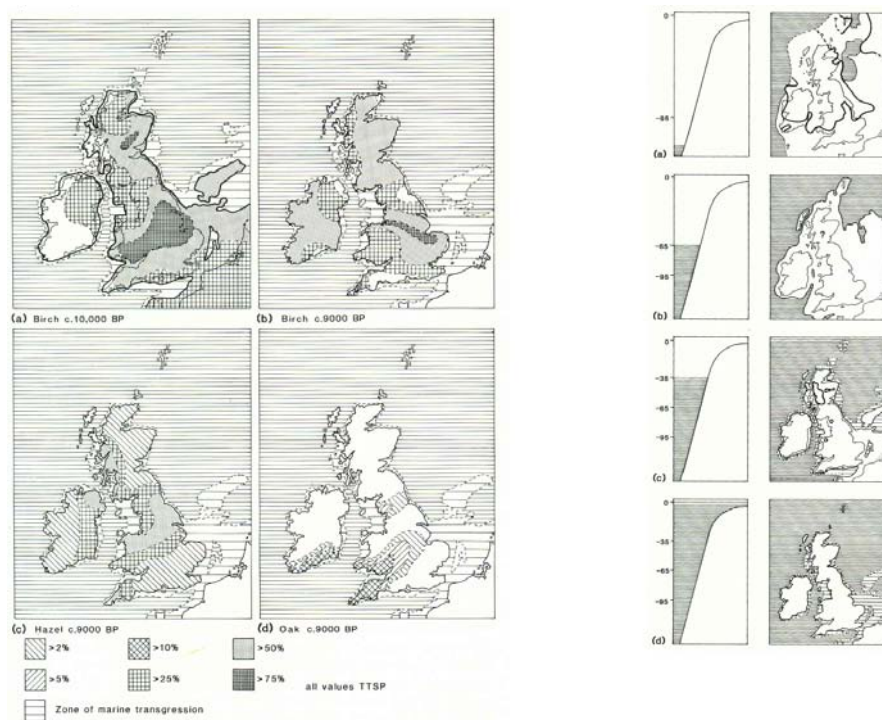
However, as Coles (1998) observes, Smith, whilst discussing the existence of archaeological

sites, neglects to observe their nature and position with relation to the former landmass.

This situation does detract from Smith's interpretation. His awareness, however, of the

data utilised to generate such reconstructions can be vividly shown through the portrayal of

"zones of marine inundation". These zones allow Smith to represent, not only the scale of

land lost at any one period, but also the uncertainty represented in the positioning of the

coastline due to sea level curve inaccuracies and the gradual nature of marine

transgression. Although Smith's maps use inaccurate sea levels, Smith's zones represent a

high level of understanding about uncertainties associated with this work. This can in part

be ascribed to Smith's background as a geographer which would have made him more

aware of the errors associated in sea level research and the correct utilisation of such

information which previous and subsequent archaeologists failed to do.

The most seminal work in reconstructing the emergent landscape of the southern North

Sea was published by Coles (1998) in *Doggerland: a Speculative Sur*vey, and succeeding

works on the Neolithic (*Doggerland's loss and the Neolithic* ,1999) and shifting coastlines

(*Doggerland: the cultural dynamics of a shifting coastline*, 2000). Coles's (1998) work

provides the most complete picture of the later prehistory of the North Sea. In this, Coles,

after labelling the landmass "Doggerland" in honour of Clement Reid (1913), drew upon all

the available archaeological knowledge at the time, and incorporated recent advances in

Quaternary science to produce a series of speculative maps (see Figure 2.6).

Coles's (1998) decision not to attempt to emulate the coastline models and isostatic models of Jelgersma (1979) and Lambeck (1995) allowed Coles to generate maps which have a significant impact upon the reader.
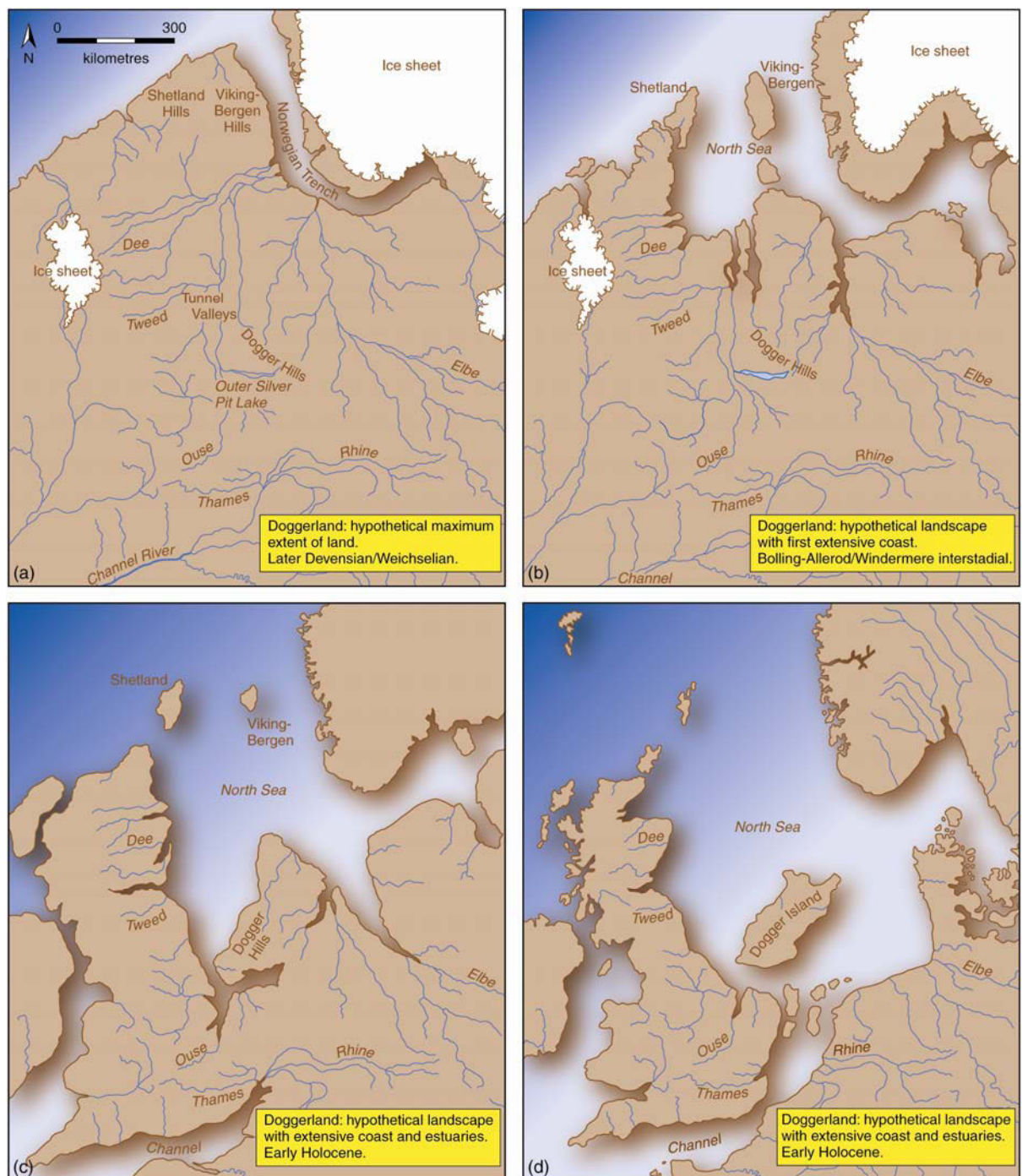
Figure 2.6 Hypothetical landscape reconstructions (after Coles 1998)

The production of maps with clear coastlines, rivers and hills allowed Coles (1998) to

explore the landscape through narrative, and to speculate upon the broad nature of the

landscape. Further, through the use of this narrative, Coles was also able to consider the

lives of the occupants within this environment in a manner previously not attempted by

archaeologists. The process allows Coles to resolve many long standing misconceptions

about the landscape. She warns that the present bathymetry does not reflect the past

landscape, and also notes that the nature of the landscape may have allowed for cultural

differences to occur. However, Coles's maps, through their accessibility, offer potential

dangers to the unwary. The specific issue with these maps is that they present an image

that is so attractive that it can mislead from Coles's stated speculative observations. This

can be seen as Coles's (1998) work reached textbook level. This has resulted in a classic

example of "cloning" (e.g. Warren 2005), where inaccuracies are introduced into texts due

to copying without consulting the original sources (Paul 1987). Gould's (1991: 166)

comment on unthinking cloning of ideas and images is perhaps best repeated "if cloning

represented the discovery of a true educational optimum... I would not object.", however it

represents the "easy way out, a substitute for thinking and striving to improve".

Probably the best example of "unthinking cloning" of Coles's work can be found in Warren

(2005) as a "reconstruction" of the landscape. The change in emphasis is subtle; from

"hypothetical" to "reconstruction". This erroneous emphasis is located in a text book

targeted at forming archaeological minds, the word "reconstruction" implies that the

landscape has been rebuilt from evidence and has a basis in fact. This is a world away from

the actual meaning of the maps which are "hypothetical" thus they are "imagined or

suggested, but not necessarily real or true" (Collins Dictionary). This change in emphasis is probably due to the persuasive nature of the image of Coles's map. The map provides a convenient way for archaeologists to fill in the inconvenient blank space in their interpretations, which are based solely upon a terrestrial Mesolithic record.

The most recent attempts of maps of the landscape of the southern North Sea have seen a shift in approach from more speculative models to large scale area mapping. The North Sea Palaeolandscape Project (NSPP) undertaken by Birmingham University saw the publication of a map in 2007 (Figure 2.7), which was the culmination of two projects and over 18 months' work (Fitch *et al.* 2005, Gaffney *et al.* 2007). The image produced by this work was fundamentally different to those produced earlier, in that it is derived from seismic geophysical data rather than bathymetric data. As such, the map reflected the presence of buried landscape features which were not currently expressed within the current seabed surface (Fitch et al 2005). This area-based map is also fundamentally different in that it expresses the real world locations of individual landscape features such as palaeochannels. However, the NSPP data does possess a limitation, due to the original data source. This issue is that the 3D seismic data does not cover the entire marine area, but is confined to deeper (generally +20m of water) more offshore areas, and, as such, retains a clear gap between the NSPP data and the shoreline. The NSPP dataset also faces resolution issues within its dataset in the shallow water areas. Heavy data noise resulting from a shallow water column marred the original survey data in the shallowest water areas. This obscured almost all the features that presumably existed in these areas (Fitch *et al.* 2007, Gaffney *et al.* 2009). However, the NSPP data is important as it shows dramatically the clear benefits

of an area based mapping approach to the problem of the Mesolithic landscape. Its

achievement in providing a map based on the consideration of a real rather than

hypothetical landscape cannot be understated.

This discussion is significant, as it highlights many of the issues raised in the introduction

relating to the Mesolithic landscape. Looking at previous maps, it is apparent that the past

images of the landscape were little more evolved beyond a blank landscape until 1998 (see

table 2.1). Certainly this is due to lack of available data. Coles's 1998 maps are significantly

better than earlier attempts, even though they use the same data. With this in mind, it is

important to remember that, until 2007, all of the maps were speculative (see table 2.1).

Whilst they were of a speculative nature, those which were based on bathymetry had some

merit, especially given the limited data available to them. However, it is significant to note

that between 1913 and 2007, the nature and position of important factors in the landscape

could only be guessed (Coles 1998).

Author/Date	Data Used to create map	Map Classification
Reid 1913	Bathymetry, Environmental evidence	Hypothetical/ Based on Bathymetry and Sample data
Clark 1936	Bathymetry, Environmental evidence, Finds	Hypothetical/ Based on Bathymetry and Sample data
Jacobi 1976	Bathymetry, Finds	Hypothetical/ Based on Bathymetry
Morrison 1980	Bathymetry, Finds	Hypothetical/ Based on Bathymetry
Smith 1992	Bathymetry, Environmental evidence	Hypothetical/ Based on Bathymetry
Coles 1998	Bathymetry, Isostatic Models, Finds, Speculation	Hypothetical/ Based on Isostatic Data
Gaffney *et al.* 2007	Seismic, Bathymetry, Core Samples	Based on Seismic data

Table 2.1 Summary of the previous maps of the submerged landscape of the Southern
North Sea
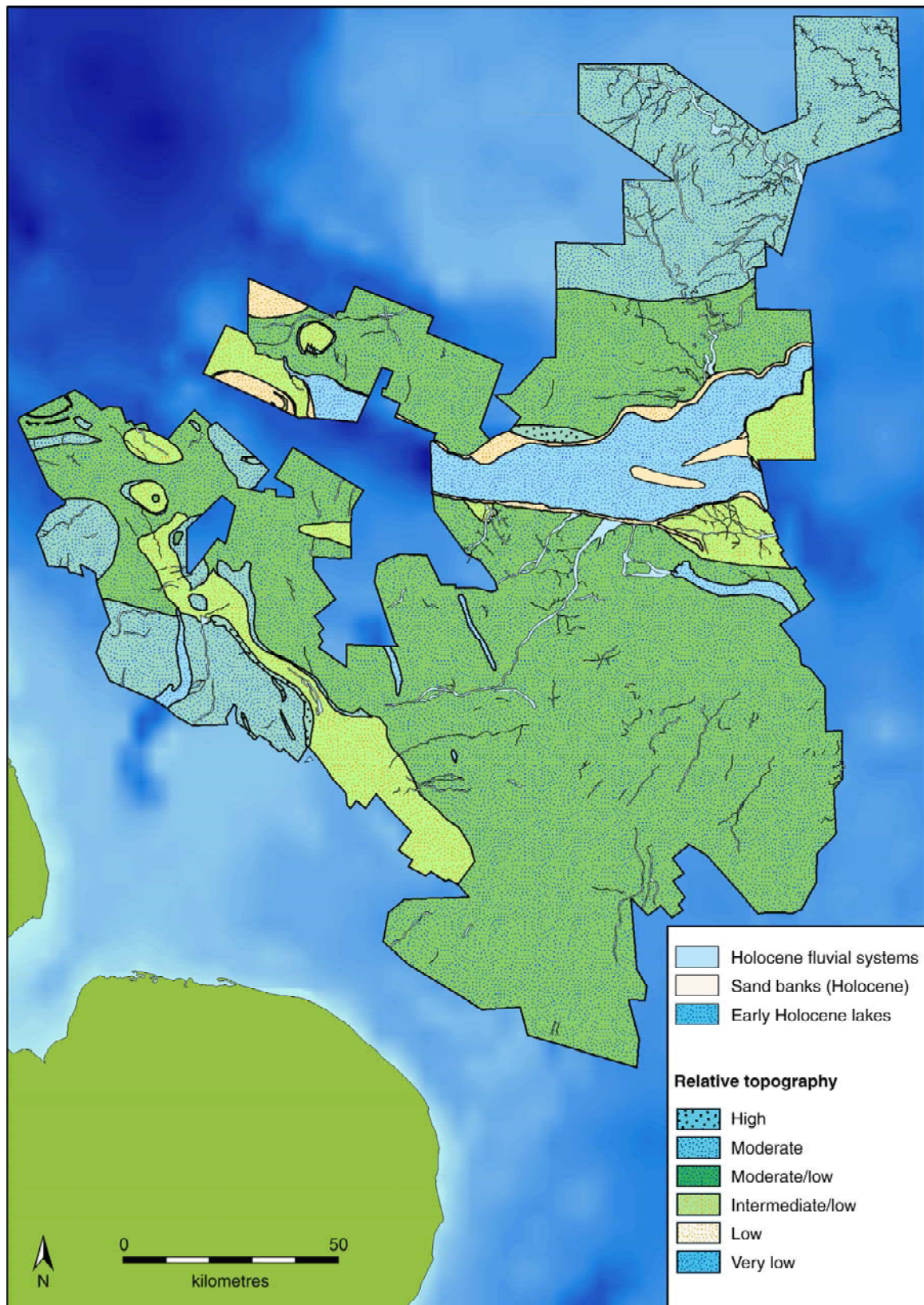
Figure 2.7 The relative topography map from the North Sea Palaeolandscape Project (from

Gaffney *et al.* 2007, Figure 7.4, p71).

2.3 The Great Mesolithic Polo: The applicability of the current terrestrial record as an analogue for the archaeology of the southern North Sea

A polo mint is an odd term of reference when applied to the Mesolithic of North Western Europe. However, in terms of morphology, its use as an analogy for the distribution of the Mesolithic record is entirely accurate (see Figure 2.8). If we examine the distribution of the present landscape, it forms a circle around the North Sea. This is reflected in the distribution of Mesolithic sites, which form a circular scatter around the void that is presently the marine zone (see Figure 2.8). It is clear, from the occasional finds from the North Sea (Verhart 2004, Glimmerveen *et al.* 2004), that this area was occupied during the Mesolithic. The question must therefore be asked "what can be learnt from this existing material from the present terrestrial sphere in respect to this study of the North Sea ?" and principally, whether there are enough similarities in this material that can be used to prepare us for future examination of the marine zone.

(A)   (B)

Figure 2.8 (B) The present landscape in the analogous context of a "polo" mint - note the gaping hole that the North Sea forms. Whilst (A) shows the distribution of some of the present Mesolithic sites around the North Sea region, the question remains, 'what was in the middle?'

In addition to this, we must also examine temporal relevance. Many of the available sites

date from the mid to later stages of the Mesolithic, with lower numbers of early Mesolithic

sites present. We must ask whether this lack of early Mesolithic sites is a function purely of

terrestrial preservation, or is something else affecting the archaeological record? Bearing

these questions in mind, it is now time to examine the Mesolithic record around the North

Sea basin.

The Mesolithic can be divided into two distinctive facies, that of the Early(10,000BP ~

8,500BP) and Later (8,500BP ~ 5,500BP) Mesolithic Periods (Jacobi 1973; Wymer 1991).

This division, based upon lithic typology, is increasingly under review (Barton 1989), with

many authorities looking towards further sub-division of these periods through

environmental stages (Barton and Roberts 2004), or in finer scale, through the utilisation of

'Microlith Assemblage Stages' (MAS) in Europe (Fischer and Tauber 1986, Reynier 2000).

However, for the purposes of this thesis, the simpler Late/Early system will be utilised to

allow a simpler link to events occurring in the North Sea Basin.

2.3.1 Early Mesolithic Phase (10,000 to 8,500BP)

Sites with affinities to both the Early Mesolithic and Later Palaeolithic do occur earlier than

the 10,000BP date Mesolithic start date. These include sites such as Stellmoor (Fischer and

Tauber 1986) or Avington VI and Sproughton (Barton 1997, Wymer and Rose 1976). The

transition to the Mesolithic from the Later Palaeolithic can now be seen as a fairly smooth

transition, rather than the traditionally held archaeological view that it was a period of

decline. The 10,000BP boundary is generally imposed by climatic and environmental

reasons, rather than any great leap in technology or culture. However, this is also

complicated by the pronounced radio carbon plateau at around 10,000BP (Stuiver *et al.*

1998, Ashmore 2004), which creates difficulties in dating this period. The production of a

reliable chronology is, therefore, difficult (Cook and Jacobi 1994). As Ashmore (2004)

observes, it is possible in these plateaux, to have a stratigraphically older sample date

earlier than a stratigraphically younger one, purely on the errors introduced by this

plateaux. This situation has been suggested by Barton and Roberts (2004) as a reason why

Thatcham III radiocarbon dates, which previously yielded dates of 10,365+/- 170BP (Q-659;

Wymer 1962), have yielded new AMS dates of 9,200+/-90BP (OxA-2848; Roberts *et al.*

1998).

However, by 10,000BP the English Mesolithic can clearly be defined in typological terms,

and can be placed into two groupings (Radley and Mellars 1964, Reynier 2000). These are

defined as the 'Star Carr type', which is dominated by broad oblique microliths (Jacobi 1978,

Reyneir 2000), and the Deepcar type, which is based on more slender microliths (Jacobi

1978, Reyneier 1997). The Star Carr type is proposed as the "older" type, although it can be

observed that both types spatially overlap (Reynier 1998). This spatial distribution is

observed by Reyneir to concentrate Star Carr assemblages in the north and west of the UK,

whilst the Deepcar assemblages are located in lowland valleys. Reyner, thus, concludes

that they were indicative of different social groupings (Reyner 1998). In the past, there has

been a trend to group British types with that of the Magelmosian of Denmark, and, in

particular, see parallels with the "Duvensee" culture (Clark 1975), often because of the

supposed affinities between the Leman and Ower point and those found in Britain and

Europe (Clark 1954). However, more fundamental differences occur in the definition of the culture. The Magelmosian culture, for example, is divided into seven stages (Becker 1951), with the Barmose phase (Johansson 1990) being comparable in age to the Star Carr and Deepcar types. However, there are fundamental morphological differences in the lithic material suggest these groups should not be linked (Reynier 2000).

This is also true of the Preboreal stage of Northern Germany (Kozlowski and Kozlowski 1979), and the Epi-Ahrensburgen of the Netherlands (Gob 1979), which both fall within this Star Carr type timeframe. There are characteristic elements of the British cultures, such as the Star Carr type trapezoids, which are lacking in the contemporary continental cultures. Additionally, the paucity of reliable dating in Europe makes it difficult to assess any comparisions (Reyneir 2000: 115). Similar links related to the Deepcar type, were used by Clark (1936, 1975) to represent cultural links across the North Sea basin to Denmark. However, recent work has challenged this (Reyneir 2000 citing Verhart pers. com.), and suggests that no exact parallels to British types can be found on the continent. This is of fundamental significance to the study of the North Sea. If two distinct groupings can be observed in Britain alone, it is likely that several distinct cultures are likely to have existed in the North Sea region, given its landscape and differing environments. Moreover, whilst parallels have been made linking Britain and Europe, none can now be claimed to be definite.

Further issues can be seen if we examine the resource base of the period. This particular topic is of importance to this thesis, since the resource base will form a significant part of

the model. The evidence for subsistence throughout Europe produces a wide range of

terrestrial resources that were utilised in the regions near to the North Sea. The Friesack

site (9,000BP) best illustrates how these resources were obtained (Gramsch 1992), with the

preservation of pine arrows and spears, used for hunting terrestrial game such as red deer

and boar. Nets and rope were also found, that could be used to procure wildfowl and fish.

A similar picture of hunting and fishing can be found at Noyen (Mordant and Mordant

1992), where eel traps and an early canoe are found alongside the remains of red deer and

aurochs.

In the British Isles the picture is similar, with sites such as Thatcham, Star Carr and Seamer

Carr (Clark 1972: Wymer 1962: Legge and Rowley Conwy 1988: Mellars and Day 1994)

showing a diverse range of hunting and gathering activities. Common prey species

throughout the British Isles include, deer (both red and roe), auroch, elk and wild pig, whilst

sites such as Mount Sandel suggests that fish may have been an important food source.

Mount Sandel also provides possible evidence of fish being preserved to provide food

throughout the winter (Coles and Coles 1995, Woodman 1985). Animal remains recovered

from the near shore regions off the Netherlands, an area which would have been

continental during the Early Mesolithic, show the extensive presence of red deer, wild boar

in the region in the Boreal period (c.9150 -7900BP) (Glimmerveen *et al.* 2004). Whilst

human consumption and use of animal resources is confirmed, with some of the red deer

material showing evidence of human processing (Kooijmans 1970, 2001, Post 2000), the

lack of recovered plant material is apparent. However, given that the preservation

potential of plant remains is poor in many environments, it is unjustified to assume that

purely meat resources were used. Indeed, it is likely that between 60 and 80% of all foods were derived from vegetable sources (Clarke 1978). This hypothesis is supported by evidence outside of Britain. Human remains from Belgium dating from this period show an isotopic signature indicative of a highly vegetarian diet (Leotard *et al.* 1999).

In more recent times, with newer excavation techniques and the discovery of more wetland sites, it has become increasingly apparent that the role of vegetable materials in the Mesolithic diet was significant. The most commonly recovered plant material tends to be carbonised hazelnuts (Mithen *et al.* 2001, Waddinton et al 2003), and even the excavations conducted by Clark (1954) at Star Carr produced evidence of this foodstuff. However, other material can be found; In the excavations at Mount Sandel, in Ireland, apple and pear seeds were recovered (Woodman 1985). The absence of plant material at many sites, therefore, is due to preservation problems or, as is more likely, a failure in the identification and recognition of material.

Whilst this evidence helps us define the terrestrial resource that would have been available, the coastal resources remain elusive. Indeed, there is little actual evidence for isotopic signature of marine resources in the diet of Mesolithic man during this period. We must, however, consider that the coastline of this extensive region and associated coastal areas has been lost. Indeed, the fact that the material utilised for these studies came from heavily terrestrial inland upland areas during the Mesolithic, suggests that we should not be surprised by such a strong terrestrial signal. This issue is not confined to Britain, with evidence from southern Scandinavia having similar terrestrial affinities (Larrson 1990).

Thus, given the lack of data from the marine area, it is not surprising that material which could illustrate the utilisation of marine resources in the Early Mesolithic period has not been recovered. This issue, therefore, is one of visibility rather than actuality. Whilst terrestrial faunal remains have been recovered from the North Sea (Glimmerveen *et al.* 2004), all of the marine mammalian material recovered so far dates from 48,500 BP to 23,500BP (Aaris-Sorensen et al 1990). No marine mammalian material has been recovered thus far for the period 10,000BP to 8,500BP. This lack of early Mesolithic coastal material is primarily a function of the isostatic change in the region (Milner 2006: 68), in combination with the erosional processes occurring both on the coast and on the seabed.

There are, however, a few existing coastal sites of that period in the terrestrial sphere that we can use to guide us. The sites in Sweden show a remarkable range of resources, utilising not only known terrestrial resources, but also marine fish, seabirds and seals as food resources (Nordqvist 1995). Other areas of Scandinavia record the presence of stranded whales in the region which could have represented a useful resource to hunter gatherers (Bang-Andersen 2003). We can infer that the importance of marine resources upon the population was fundamental, even leading to suggestions of fixed coastal territories (Nordqvist 1995). As the North Sea region, by inference, possessed similar resources to the known sites in Sweden, it is highly probable that the coastal regions of this area may have possessed groups of hunter gatherers whose resource strategy was centred upon the utilisation of these resources. It is also important to note that, to reach southern Sweden, these groups must have passed the coastline of the North Sea emergent plain, and therefore a possible similarity in resource strategy is not unreasonable.

The influence of marine resources on the early Mesolithic is important. In Scandinavia, seal bones can be observed for a distance into the interior, suggesting trade, exchange of food material or seasonal movement (Kvamme and Jochim 1990). Clark (1952), in his synthesis of stone age hunting, regarded seal hunting as "an activity of vital interest" to stone age communities. The drowning of extensive plains within this region would have produced large areas of coastal shallows. Clarke (1978) observed that these would have been richly productive in edible molluscs and crustacea, whilst Coles (1998: 74) observes the importance of the area to migratory birds. Information on the procurement of these species is missing from the current early Mesolithic record due to submergence.

The diversity of resources within these coastal areas has implications for the cultural affinities of this population. As Coles (1998: 74) observes, these coastal territories would have been able to support high population densities. These would have been culturally different to those currently observed within the Mesolithic record. However, Barton and Roberts (2004: 353) question whether the extensive early Mesolithic territories would have included coastlines. Thus, they reason, there would have been little need to utilise coastal resources during the Early Mesolithic. However, this argument is based on the absence of evidence in the modern terrestrial sphere. It is only through the procurement of material from the coastlines in the present North Sea that such an argument can be resolved. This situation arises from the submerged and distal nature of the coastlines, which cause them to be overlooked in the current archaeological record (Bailey and Milner 2002). Therefore, whilst the extent of terrestrial evidence allows us to suggest something of the diet for the upland terrestrial areas of the early Mesolithic, the evidence from a large part of Europe for

the utilisation of Marine resources is lacking. Where the coastal zones are present, it is apparent that such resources are used (Nordqvist 2000). Using this as a basis, there is a strong case to suggest the utilisation of marine resource, during the Early Mesolithic in the North Sea region.

2.3.2 Later Mesolithic Phase (8,500BP to 5,500BP)

The Later Mesolithic in Britain is largely seen as divergent from that of Europe. Jacobi (1976) proposed that this divergence was related to the submergence of parts of the North Sea, and the increased difficulty in connections between Europe and Britain. However, as Funnell (1995) and Coles (1998) observe, Britain did not become an island until c7000 BP, and, therefore, it is unlikely that this was the driving force behind the changes in technology at this period. Clark (1975) utilised the similarities within Mesolithic technology to suggest that the Ertebolle culture of Denmark was another phase of the earlier Magelmosian, and thus linked the British and Danish archaeological record through a common technological ancestor. Palmer (1977: 60) argues against this situation, and observes the genuine cultural differences between the Maglemosian and Ertobolle. Palmer notes that, given these differences, any supposed cultural link is therefore tenuous.

The most likely driving force upon cultural evolution during the period is environmental change, and the environmental shift from the Boreal to Atlantic climate. Clark (1955) observed many similarities between the British record and the 'Sauveterrain' from south western France (1944). Mellars (1974), however, observes that there are equally close parallels in Belgium that are suggestive that the North Sea emergent plain could have been

facilitating cultural contact, but he notes that these parallels could not necessarily be taken

to mean a movement of people.

The existence of islands in the North Sea would not necessarily mean that they were

culturally isolated from Britain and the rest of Mesolithic North Western Europe. The

impact of these islands as "stopping off" points between Britain and Europe is important,

and the potential "push" caused by the marine transgression may have led to the

colonisation of other areas. The colonisation of Scotland and Norway by communities from

the North Sea is a possibility (Bjerk 1995, Bang-Andersen 2003). Coles (2000) observes that

some of the longer lived islands may have proved a source of resistance to the adoption of

farming, and may explain the slower adoption in Britain and Ireland.

The possible evidence for cultural links between areas of north western Europe must take

place in the framework of the ongoing submergence of the North Sea emergent landscape.

Most importantly, this is recorded in the palaeocoastlines of that period. These are often

closer to the present terrestrial sphere and, thus, easier to access. The increasing visibility

of the coastline within the archaeological record (Coles 1998) is due to the isostatic

rebound that affects these areas, moving these coastal sites up and away from the erosive

influences of the sea (e.g. Coles 1971, Mellars 1987). This change positively influences the

visibility of marine resources, with the presence of shell midden sites occurring in the

British record (Westward Ho!, Churchill 1965; Oronsay, Mellars and Payne 1971; Culverwell,

Palmer 1976; Lough Swilly, Milner and Woodman 2004), as well as in Denmark and other

European Regions (Norsminde, Andersen 1989; Brovst, Andersen 1989; Meilgard, Liversage 1992; El Collado, Aparico 1992; Sado, Arnaud 1989; Hoedic, Pequart and Pequart 1954).

The shift towards the increased visibility of marine sites is further illustrated by the presence of the near shore Danish marine sites including Tybrind Vig and Mollegabet II (Andersen 1985; Gron and Skaarup 2004). Sites in these areas currently number c 2,300 (Fischer 2004). Britain's only in situ prehistoric marine site, Bouldner Cliff, dates from this period (~8,345BP Momber 2004), although a number of intertidal sites such as Goldcliffe, in the Severn Estuary, (Bell 2000) also fall within this period. Indeed, in comparison to the Early Mesolithic, the range and scope of environments recorded in the Later Mesolithic record around Europe is impressive. This increased record reveals a more complete representation of marine resources that helps portray a more complex picture of Late Mesolithic life.

In terms of resources that these Late Mesolithic sites draw upon, the image portrayed appears, at first glance, more diverse. However, this is partly due to a representation of the vastly increased visibility of the coastline during this period. The increasingly marine isotopic signatures within the skeletal material for the period (e.g Cnoc Coi, Richards and Mellars 1998) clearly highlight an increased usage of marine resource. This could reflect an increased archaeological visibility of communities using marine resources, or an actual change in resource procurement. As a comparison, the Danish Storebaelt presents a similar picture. Pedersen (1997), states that the isotopic evidence from the local skeletal material shows that 75% of their food resources was coming from the sea. However, as Milner *et al.*

(2004) rightly argue, we must proceed with caution before ascribing this model to the whole Mesolithic. Milner observes that the concentration on coastal sites leaves little understanding of what happened in the interior areas (Milner 2006). There are many instances of fully terrestrial or mixed isotopic signatures within the skeletal record, which show that other patterns of resource utilisation exist (e.g. Milner 2006).

The visibility of estuarine environments for this period, however, shows the diversity of opportunities to hunter gathers. Faunal resources are much more visible in these areas. This increased visibility is also achieved through the preservation of animal tracks (Liverpool Bay, Huddart *et al.* 1999; Severn Estuary, Allen 1997). As Bell (2000:79, 2007) observes, this allows not only a validation of the faunal evidence on and off site, but also provides valuable insights into herd composition and hunting practices. For example, Bell observes that in the Severn Estuary, the second most frequent taxon represented by tracks (auroch) is absent in the faunal record at the Mesolithic site. However, wild boar, an animal that is not present in the track record, is found in the skeletal record at the Mesolithic site. This observation illustrates the complexity of resource procurement strategies in the Later Mesolithic.

In Europe, evidence for temporal changes in faunal use exists, from the sites of Skateholm I and II in Denmark. Skateholm I displays a use of seal, saltwater fish and wild boar, whilst the later Skateholm II shows a utilisation of roe deer and freshwater fish (Larsson 1984). Clearly, there appears to be a change in resource use in this area in the Later Mesolithic. This situation may lead us to consider how the range and scope of subsistence changed.

Milner (2006) argues that looking for temporal and spatial patterns within sites will help little in answering these questions. She argues that archaeologists should address these issues at a regional scale. This can, in part, be realised through an examination of shell middens. Shell middens are probably one of the most eloquent sources of evidence for the Late Mesolithic. Any early Mesolithic precursors of these features for Britain are now submerged (Chatterton 2006). Therefore, in Britain at least, these features are, at present, only found in the Later Mesolithic. Shell middens, whilst representing rubbish heaps for marine based communities, also contain material from terrestrial resources. The idea of shell middens representing a purely marine diet is therefore misleading. Bailey (1978) observes it would have taken 31,360 limpets to provide the same calorific intake as a single red deer, indeed, it has been suggested that the use of molluscs occurred during periods of crisis (e.g. Bailey 1982, Mannio and Thomas 2002). This should not be over emphasised (Mellars 2004), as molluscs represent a simple and obvious source of food. Indeed, in Denmark, the utilisation of these resources is no longer seen as indicative of crisis before the inception of farming (Andersen 1973).

This picture can be illustrated by the isotopic evidence, with five out of six human finds at Cnoc Coig on Oronsay in Scotland suggesting a diet of 90% marine food (Richards and Mellars 1998). The position of this site upon a small island with limited terrestrial resources must be considered (Richards and Mellars 1998) (cf. Mithen and Finlayson 1991) as it represents a valuable analogy for human subsistence during the final stages of existence of the North Sea landscape. A further example, Oronsay, can also be utilised to inform our understanding of human habitation of the landscape. Oronsay has produced a model of

permanent or semi-permanent human occupation upon an island only six square

kilometres in area, and is based upon the utilisation of marine resources on that island.

However, Mellars (2004) acknowledges that resources may have also been procured on

other islands. Given the vast nature of the southern North Sea alone (80,000Km^2), we must

consider this in light of the landscape fragmentation due to submergence in the Later

Mesolithic. The submerging North Sea landscape must have produced a multitude of

islands broadly similar in size to that of Oronsay. If semi-permanent occupation was

possible on Oronsay, then the idea of a coastally based human culture being active in the

North Sea is not unreasonable. Therefore we, perhaps, should expect to find similar

structures such as shell middens in the North Sea.

This hypothesis is supported by Coles (1998) who proposes the idea that the Doggerbank

forms an island at the termination of the early Mesolithic. Coles suggests that a resident

population for this island is far more likely than seasonal visitors. Human presence on the

Dogger Bank is at least confirmed in the Later Mesolithic at 6,050 BC (Coles 1998 citing

Andersen pers. comm.). However, with a complete absence of diagnostic material from the

southern North Sea, there is no evidence to support an understanding of the culture of the

area (Verhart 2004). Further, the absence of the emergent North Sea region, once again,

acts as a significant gap in our understanding of the availability and utilisation of resources.

Thus, whilst the evidence is fairly good for Scotland and Scandinavia (e.g. Coles 1971), this is

not the case for many parts of England and Europe. This is especially apparent for the

period 8,500 to 7,000BP. It would be difficult, therefore, to consider regional resource

strategies for areas such as England and the Netherlands when large parts of the optimal

environments, and hence resources, are absent from the archaeological record. For now, at least, the archaeological record for this region has an "absence of evidence"; It must be appreciated that although evidence for human activity is not presently extant, this does not preclude its actual discovery.

2.4   Discussion: Cultural Implications of considering the southern North Sea as the heartland of north western Mesolithic Europe

As previously observed, the interpretation of the Mesolithic has been driven by a land-biased "outwards in" perspective. This can be seen to be a product of a lack of data. Yet, when the area has been considered in its own right, an abundance of resources must have been present. This has led to the region being proposed as the "Heartland" of the Mesolithic in North Western Europe (Clark 1936), or as an area of "greater" population (Morrison 1980: 118). In terms of land area and resources, the region has been considered to have been highly desirable to hunter gatherers (Coles 1998: 75, Morrison 1980:118), with the present terrestrial record being regarded as "marginal lands" (Morrison 1980). The school of thought that advances the North Sea as an ideal place to live is described by Coles (1998), as representing "geological archaeologists" (e.g. Smith, Wymer and Kooijmans : Coles 1998, 50). Coles concludes that their background, has given them confidence in the emergence of the North Sea. This difference in approach is fundamental to their interpretation, as it has allowed these people to appreciate the coastal and estuarine resources that must have been present in the region, yet are not present in the current archaeological record.

The landscape's proximity to the sea would also have provided access to coastal resources, and given the continental nature of much of Europe at that time, much of this coastal resource would not have been accessible to the inland areas. The presence of major rivers and their estuaries would also have provided an abundance of resources (Clarke 1978). This idea is supported, in part, by the variety of dwelling structures that are now being discovered throughout the North Sea region, and which date to the early Mesolithic. At Howick, in Northumbria, a large and complex dwelling was discovered, which can be demonstrated to have been occupied for at least 100 years at the end of the early Mesolithic from 8,700 to 8,600 BP (Waddington *et al.* 2003). This structure is not unique in Mesolithic Britain, as evidenced by the recent discovery of a broadly similar structure in East Barns in Dunbar (Scotland), dated to 8,300BP (Gooder 2007).

Similar structures can be found in the Irish Mesolithic at Mt. Sandel, in County Derry, (dating from 8,900 to 8,400BP, Waddington et al 2003). The large numbers of post holes at Mount Sandel suggest a series of dwellings, which vary slightly, both temporally and spatially. These had been erected over an artificially created hollow, within which a series of hearths were located. Given the temporal and spatial range of these structures, it is probable that a tradition of building substantial dwelling structures existed within the region from Scotland to the Low Countries (Waddington 2007). The position of the Howick site next to the North Sea emergent plain suggests that the tradition of building such structures existed in the North Sea plain during this period.

The remains of the hut at Howick indicate a substantial dwelling occupied over an extended period of time. This information is further augmented by the presence of storage pits outside the dwelling. This style of occupation shows that favourable sites were, at the very least, returned to over long periods of time so long as resources were available. Given the postulated resources of the southern North Sea and the range of favourable environments, such an occupation could also be expected to have occurred there. Boomer *et al.* (2007, 102) consider that this tradition was initiated as a response to the displacement of 'North Sea' populations. This suggestion is consistent with the idea of the southern North Sea being an area of greater Mesolithic population. On examination of the available landscape, the landscape loss would have been unlikely to be significant locally (see Boomer *et al.* 2007, 91 - Figure 3 for an illustration of this). Looking at the scale of landscape loss presented by the sea level models (e.g Shennan 2000 and Boomer 2007), is it apparent that landscape changes of sufficient size to cause social stress must have therefore been occurring elsewhere, most probably in the North Sea area. Therefore, the questions posed by Howick may remain unanswered until the first in situ Mesolithic occupation sites are found in the North Sea. However, the argument is important, as it highlights why the area is so significant. It also shows why research into this area is so important and needed. Further, Howick also serves to emphasise the probability that the current terrestrial record may be limited in its application to the southern North Sea.

2.5 The need for an "inwards out" approach and the effects of a terrestrial bias on research

As observed previously (see section 2.3), the archaeological tendency to link both Britain and Europe in cultural terms has proved irresistible to archaeologists (e.g. Jacobi 1976). This approach has been challenged, but the basis from which this is being performed remains the available terrestrial evidence. Whilst this has allowed a consideration of the southern North Sea, it has only been with an eye to understanding the terrestrial record. Archaeology's response to the prehistoric marine archaeology of the southern North Sea is "we are interested, but it appears difficult". This is not surprising; there is a significant lack of data to support research in this area. This is combined with the Mesolithic research community in Britain at least, possessing an overwhelming archaeological desire to find another Star Carr, rather than tackle the broader issues at hand and search for more diverse forms of evidence (Milner and Woodman 2004: 4, 6). Milner and Woodman (2004: 6) argue that structures like Howick provide a balance to Star Carr in our interpretation. However, the fundamental issue is how significant amounts of the landscape are not represented in our interpretation of the Mesolithic period.

This focus on the land has restricted archaeological interpretation. An example of this is Barton and Roberts (2004: 349) who use the absence of evidence to support their assertion of a lack of marine resource utilisation in the Early Mesolithic. An alternate approach to dealing with the problem of early Mesolithic marine resource utilisation is stating that it "might occur", but is "difficult to locate or absent" (e.g. Conneller and Warren's Preface (2006), but contrast Flemming 2004 who illustrates this situation is changing). Whilst

acknowledging that the resource exists, it supports an archaeological position which fails to acknowledge the cultural diversity that the North Sea must have possessed. Much diversity must have resulted from access to different resources (Milner 2006: 61, Parker Pearson 2003), which would have further been enhanced by marine transgression (Bjerk 1995, Coles 1998). The implications of an advancing coastline upon the occupants of such a region must therefore have been profound (Mithen 2003, contrast Clark 1975, 28). This can be seen through the influence of water on Mesolithic cultures which is present within the terrestrial record (Conneller and Warren 2006).

The hints from the extant archaeology are tantalising, indeed it is a wonder that they have not induced archaeologists to look further out to sea. It appears we are entrenched in our terrestrial bias and "outwards in" perspective imposed by studies of the past. What is required to understand the North Sea is an appreciation that what is presently land probably only represented the periphery of the Mesolithic zone of North Western Europe (Morrison 1980). This must certainly be the case for the early Mesolithic, and probably remains so into the Later Mesolithic. What is therefore required is a new approach, looking "inwards out" from the marine sphere. Smith (1992) perhaps is a good example of the approach which forms the background to most of the interpretations of this "inwards out" style of thinking. The use of analogous and contemporaneous resources allows Smith to understand the resource base that could be accessed by a community occupying part of the North Sea landscape. Further it allows for an appreciation of the attractiveness of these environments. This is achieved by considering the landscape though environments, and this approach, therefore, considers the effect of the coastline on the available resources.

Smith acknowledges this could be argued as environmental determinism. However, he

suggests that hunter gather communities are affected by the presence/absence of

resources and that such an approach is valid. Another argument to support this approach is

that it is working from the only available dataset. The environmental evidence is the only

information available for archaeologists to work with across this area. With the absence of

archaeological sites from the offshore marine sphere, how else are we to proceed ? There

are only a very small number of loose finds in the whole of the southern North Sea to guide

our research, and these are further limited by their provenance, which is often unknown

and poorly located.

2.6   Synthesis: Implications of current interpretation on the aims and objectives of this thesis

In this chapter, we have seen the affects of the current interpretive approaches to the

southern North Sea and its landscape. The fate of the landscape and its associated

archaeological research is, perhaps, best summarised by Clement Reid. Reid perceptively

predicted that "the archaeologist is inclined to say that [these deposits] belong to the

province of geology, and the geologist remarks that they are too modern to be worth his

attention; and both pass on." In the case of both the landscape and archaeological

research, this has certainly been the case until recently. However, new research into both

the landscape (Gaffney *et al.* 2007), and the archaeology in surrounding areas (e.g.

Waddington 2007) has opened up further opportunities to understand this region. This has

been supported by recently developed approaches to the Mesolithic, which are less site based (Milner and Woodman 2004:6).

All of this new information lends to the conclusion that our current interpretation of the Mesolithic of the southern North Sea is too simplistic. The constraints of the limited evidence that has been available, combined with the "cutting and pasting" of information from the terrestrial sphere, has significantly hampered our understanding of this regions' archaeology. Conneller (2004a) attempts a solution to this issue through a humanistic approach. Conneller incorporates an understanding through narrative, an approach that focuses on experiences (Conneller 2004a: 48, 53). Unfortunately, this tells us little about the landscape and its actual culture. Even these attempts to move Mesolithic archaeology away from more traditional approaches are still bound by the terrestrial evidence. Yet when the North Sea is understood in its landscape context (Appendix 3), it becomes an ideal place for occupation and resource procurement (Clarke 1978, Morrison 1980, Coles 1998). Given this potential, it is likely that it would have presented an attractive and diverse environment to Mesolithic populations (Appendix 3). Certainly, this landscape would have proved more productive than the areas presently utilised within our current understanding of the Mesolithic. If we consider this information, it demonstrates that a landscape approach to the research questions posed by this thesis (see Chapter 1) is appropriate.

CHAPTER 3

METHODOLOGY

3.1   Introduction

The purpose of this chapter is to outline the methodology that will be implemented in this thesis to address the aims and objectives discussed previously. As identified in Chapters 1 and 2, it will be necessary to generate several of the datasets required directly from 3D seismic data. This chapter will start by outlining the key datasets, before proceeding to discuss the detail of the methodology to be applied. As the datasets generated will build upon each other, the methodology will be sequentially ordered to reflect the workflow undertaken.

The key dataset from which several data layers will be derived, in part or in whole, is 3D seismic data. Traditional seismic data has been used for archaeological purposes some time. However, the use of 3D seismic data in this fashion is relatively new. This section will work towards Aim 1 of this thesis through the generation of landscape data and identify key features within it. The use of a suitable sea level curve will assist in the understanding of the effects of environmental change upon this landscape.

3.2   Brief introduction to the archaeological uses of marine seismic data

The exploration of submerged prehistoric landscapes that are supranational in scale and which may be masked by tens of metres of water provide archaeologists and heritage

managers with a unique set of technical and methodological challenges. Despite this,

marine archaeology has recourse to a variety of data sources when exploring the extensive

palaeolandscapes associated with the coastal shelves of North West Europe. These,

primarily, are derived from seismic reflection profiles collected for the investigation of near

seabed features or deeper hydrocarbon exploration.

These datasets are acquired for a variety of purposes and have differing characteristics and,

as a consequence, may vary in usefulness for archaeological applications. The requirement

for regionally extensive data is such that, aside from precision and contiguity, issues of scale

and resolution are of considerable importance. Consequently, there is often a choice

between differing seismic reflection data types. It is entirely possible that specific surveys

may not be appropriate for use by archaeologists, largely as a context of the available data

resolution or scale of survey. The decision to use such data will therefore depend upon

archaeological requirements and so, in many ways, the position is not so different in

terrestrial archaeology where there are often valid reasons to choose spatially extensive,

low resolution sensors in preference to high resolution sensors which may operate only at

site level.

High resolution 2D seismic profiling is traditionally used by archaeologists to provide

information about the nature of the buried landscapes to archaeologists. Velegrakis *et al.*

(1999), working in the Poole Bay area in the U.K. provides an example of how 2D profiling

can be utilised to build up a picture of a buried landscape. In this study, seismic lines were

surveyed in a grid pattern, with line spacing ranging in the 100's of metres. Similar

examples have been undertaken in the marine environments of the Danish Storebaelt (Bennike *et al.* 2004). In these surveys it can be seen that whilst 2D seismic data provides important information on the architecture of the sedimentary system, it suffers from a weak three-dimensional framework that is caused by the necessary interpolation between profiles. The weakness of the 2D seismic data approach in comparison to that offered by 3D seismic data has been recently demonstrated by a study of existing 3D seismic data in the same area as Velegrakis (Thomson and Gaffney 2007). Whilst Velegrakis' study shows some of the palaeovalley complexes positioned in the right locations, the 3D data reveals that many have been erroneously joined or positioned at the wrong angle. These errors are most likely to have been caused as a function of the necessary interpolation between the 2D lines.

The use of 3D seismic data to investigate palaeolandscapes has been established by the oil industry (North 1996, Posamentier 2000). However, its use in archaeology has been more limited. As the oil industry is interested in changes of lithology, especially those associated with palaeochannels (e.g. Posamentier 2004, Walls *et al.* 2002 and Peyton *et al.* 1998), the data and techniques are tuned to observe these effects. Primarily, the investigation of Quaternary sediments using 3D seismic data has focused upon glacial tunnel valleys and observations of their morphology and infill (e.g. Lonergan *et al.* 2006, Praeg 2003, Long and Stoker 1986). The use of 3D seismic in identifying features of archaeological interest, and especially Holocene landscape features, remains limited. Praeg in 1997, however, recorded a Holocene fluvial channel, whilst looking for glacial features in 3D seismic data. Although the seismic data was limited by poor vertical resolution, reflector evidence suggested an

age of between 18-8Ka BP. This study's proximity to the U.K sector strongly suggests that similar Holocene fluvial landforms could be located in U.K territorial waters.

Using similar data over an extensive area, the North Sea Palaeolandscape project (NSPP) applied an archaeological perspective to landscape investigation, to reveal the nature of the preserved Holocene landscape of the Southern North Sea (Gaffney et al 2007, 2009). Thus it was apparent that 3D seismic data offered an opportunity to investigate the Holocene palaeolandscape within a strong three dimensional framework. This thesis adopts and develops this approach.

3.3   Brief introduction to the archaeological uses of GIS

The increasing application of geographic information systems (GIS) to manage, manipulate and display spatially referenced data sets within archaeology, and related disciplines, has been a major trend over the past decade (Gaffney 1992, Gafffney and Stanic 1992, Chapman 2006, Connoly and Lake 2006). A similar trend is discernable within hydrocarbon exploration where the ability of GIS to handle a variety of spatial data, in conjunction with its analytical capacity, has made GIS an invaluable tool for petroleum exploration (Gaddy 2003). Further, the ability of a GIS to visualise and manage data throughout a projects life has proved invaluable to the petroleum industry in recent times (c.f Lawley and Booth, 2004). This thesis utilised this interpretative ability to analyse the generated spatial data within an ESRI Inc. ArcGIS database.

Despite this situation, the scale of data use and the incorporation of non-traditional digital

data sources proved problematic during the course of this thesis. It is notable that the use

of GIS within the petroleum industry has run in parallel with the development of 3D

modelling systems, alongside remote sensing packages, that link interpretive and

geophysical data (Gaddy 2003, 1). Softwares including SMT Kingdom, utilised by this thesis,

are able to image vast and complex geophysical datasets, as well as facilitating the mapping

and management of petroleum data within an easily visualised environment. The

requirements of the petroleum industry have produced highly flexible interpretation

packages and industry requirements are very similar to those of the NSPP (see Thomson *et*

al. 2007). The utilisation of these well developed and reliable packages was therefore highly

desirable and applicable to the archaeological analysis undertaken by the project.

Within marine archaeology, the use of GIS to assist in archaeological management is

fundamental (Groom and Oxley 2001, 56). Distributional analysis of marine and associated

resources, or even analysis of the absence of evidence, permits the targeted use of

resources in curatorial terms and provides a greater insight into the structure of the marine

database (Groom and Oxley 2001; Allen and Gardiner 2000, Fitch *et al.* 2005, 194). The

utilisation of geophysical information within a GIS is also well understood within the

archaeological community (e.g. Buteux *et al.* 2000, Gaffney *et al.* 2000). This has proved

invaluable when monitoring landscapes that contain poorly understood archaeological

resources (Chapman *et al.* 2001). In areas where archaeological survey and interpretation

is severely limited by the prevailing physical environment, the ability to combine data

sources including geophysics, physical samples and archaeological material, to provide a proxy environment for interpretation is crucial.

3.4   Introduction to key datasets.

The 3D Seismic dataset used here is derived from sectors J07 and J08 of the PGS Southern North Sea Mega Survey (see Figure 3.1). This data set was created from the merging of released oil company and non-exclusive 3D seismic data sets. This data set offers therefore one of the world's largest coverage of 3D seismic information. A good example of one of these surveys, which have been merged, is Q44-99 (PGS 2004), which was collected by the PGS survey vessel American Explorer in 1999. This survey covers an area of 1083 square kilometres, most of which is located in the northern half of the sector J08, with the data being collected using two LL XT Bolt airguns for seismic sources and data being collected by six 3600 metre streamers, which gives the data its resolution and allows the data to be bin spaced at 12.5metres.

The surveys used within this study were provided pre-processed using zero phase time migration to allow all the different surveys to be correctly aligned. However, Edwards and Witney (2002) note that varying data quality between surveys can require the original data source to be reworked to prevent mismatches. They note that this reworking allows the data of subsurface features to be visualised at a scale and resolution that was previously unavailable. Edwards and Witney (2002) also note that this processing also pushes current computing technology to its limits, in terms of storage and processing power.
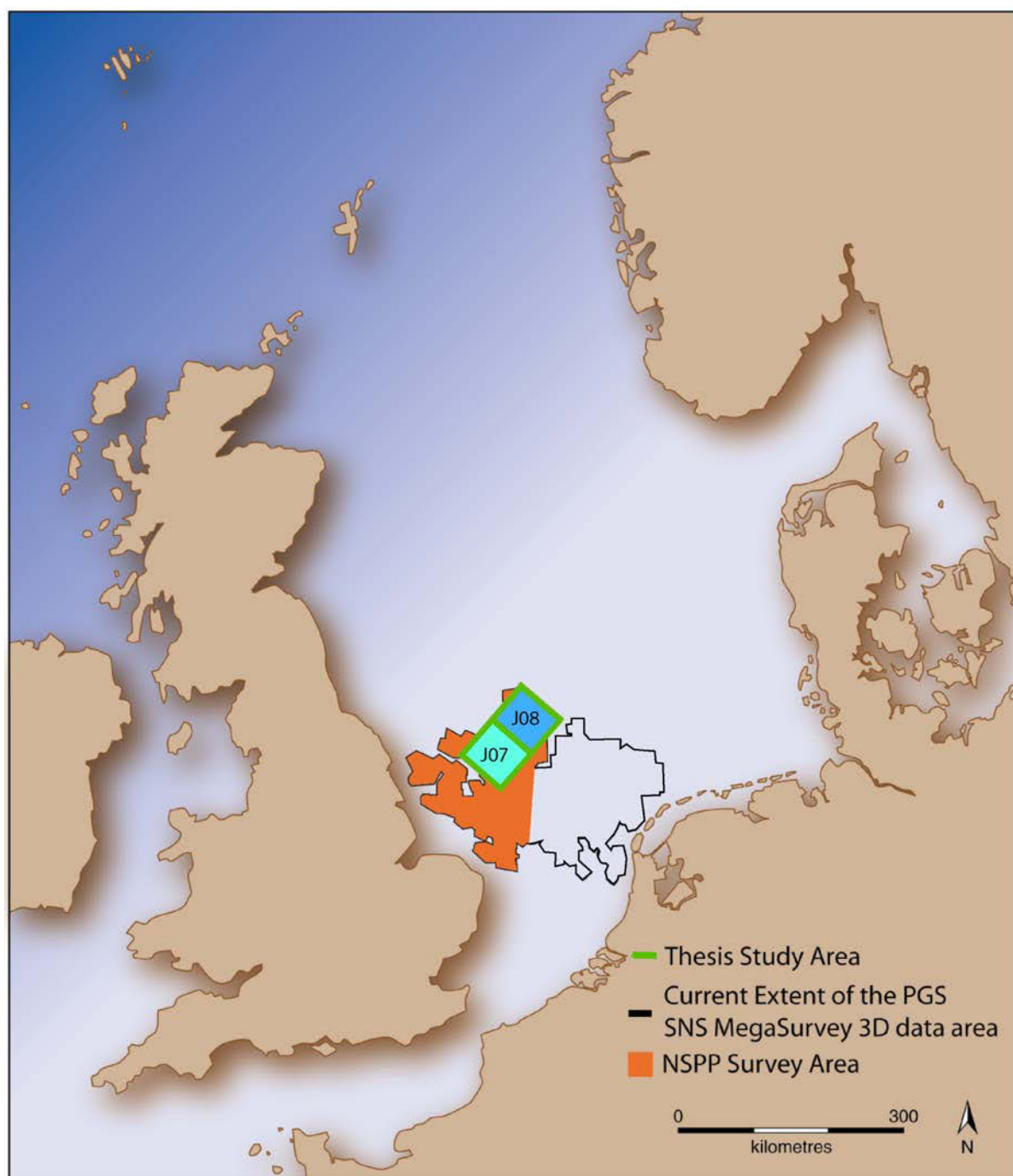
Figure 3.1 The location of Data blocks J07 and J08 within the NSPP and Megasurvey data areas.

The 2D seismic profiles used in this thesis for the purposes of data verification originate from the Gauss 159B survey, undertaken as a co-operative effort by the Geological surveys of Great Britain, Belgium, the Netherlands, Germany and Denmark in 1990. This was undertaken as part of "The Southern North Sea Project", with the aim of studying the Quaternary succession within the area. The data from this survey was collected using a Texas Instrument Sleeve gun as a seismic source, with the data being collected on a 12 Channel ministreamer. The resultant seismic data was processed by Geco and BGS (Edinburgh) with the profile data used in this thesis being obtained directly from BGS Edinburgh. The results of the "Southern North Sea Project" made it possible to produce an estimated geological model of the Southern North Sea (Fannin 1991). However, whilst the results from the 2D profiles for the British sector remain unpublished, those of the Danish sector have been published by Salomonsen (1994), and clearly showed buried Holocene river channels.

In addition to the seismic datasets other data sources were consulted to provide additional background information and assist detail correlation. Digital Bathymetry was obtained from the BGS (British Geological Survey) in the form of their Digbath250 data product. DigBath250 is a vector digital bathymetry set for the United Kingdom marine waters, and provides a regional scale digital bathymetry as a primary dataset for geographic information systems (GIS), mapping and modelling of the seabed and sub-seabed. Produced to a specification for non-navigation applications only, the BGS provides this dataset in standard GIS and CAD formats in a Latitude/Longitude co-ordinate format with the WGS84 Spheroid being used. The Digbath250 data provides contours at 10 metre depth intervals from 0m to

200m, for the whole of the study area. Bathymetry can be thought of as the underwater equivalent to altimetry, and provides a map of the current seabed surface in terms of depth. This does not however, provide an image of the palaeolandscape of the region, since this map includes features and effects produced by post inundation processes such as sedimentation and erosion. These can produce significant changes in relief in the bathymetric map (Bell et al 2006, 14, Fitch et. al 2005). In the course of this thesis bathymetric data was utilised to allow for an observation of the present position of identified features in relation to the present seabed surface. To this end bathymetric data was purchased from the British Geological Survey (BGS) for the southern North Sea sector, and provided under Licence 2004/109DB in ESRI Shapefile format. Coastal information was obtained for the GIS to accompany the bathymetric datasets. This is available free of charge from the Defence Mapping Agency's (DMA, now the National Geospatial-Intelligence Agency (NGA), www.nga.mil) World Vector Shoreline product. This provides world-wide coastal information, and is suitable for map scales close to 250,000 and utilises WGS 84 as its spheroid. More information about this product can be found in Soluri and Woodson (1990).

The location of seismic surveys and their spatial extents is an invaluable data layer. The seismic data acquired from PGS consists of a continuous coverage, because of the merging of a variety of component datasets. However, it is useful to understand the source of the underlying surveys. This data allows the assessment of the vintage and seismic source type, which are required for quality evaluation. For this purpose, information was obtained from DEAL UK (http://www.ukdeal.co.uk/). Deal UK is a free public service which provides

information upon the exploration and production of oil and gas within the United Kingdom Continental Shelf. This information is constantly updated to take into consideration the continuous nature of the survey in the area. This study utilises information obtained in 2006, which has now been superseded.

The thesis area under study straddles two of the main geological mapping zones, commonly known by their shipping areas as "Silverwell" and "California". For both areas a variety of mapping was available, covering various different aspects of the geological history of the area. The solid geological map covers the solid hard rock geology which forms the basement of the area, as well as controlling the structure of some of the features in this area. Given the thick Quaternary cover of this area (Cameron *et al.* 1992), these maps were of limited use to the archaeological mapping. However, they do provide a useful background for the analysis of larger landscape wide variations. The second set of mapping is the BGS Quaternary Sheets. This set of maps provided an image of the probable Quaternary geology, stripped of the most recent sediments (i.e. Holocene). These are extremely useful as they provide the basis of the main structure of the Holocene landscape. Most of these Quaternary sediments acted as the parent material for later deposits. However, these maps are limited as they ignore the earlier Holocene, ignoring archaeologically significant landscape changes. A further limitation is that these maps are based upon the results of scattered coring and limited 2D survey (Cameron et al 1992), thus introducing the possibility of interpolation errors. The final series of maps are seabed and sediments maps. These provide an overview of the most recent sediments at the seabed surface. Whilst these do not directly provide information on the archaeological landscape,

these maps do provide invaluable information on the depth of sediments and hence delimit the areas of possible archaeological preservation.

3.5   Methodology Outline

The datasets used within this study comprise a series of vector and raster layers. As detailed previously, all of these layers will provide information which will assist in the achievement of the thesis objectives (Figure 3.2). The process is outlined in the following Figure 3.2, and is linked to the sections of this chapter. As has been observed previously, many of the supporting datasets have a large spatial coverage, whilst are often coarse in scale and resolution.
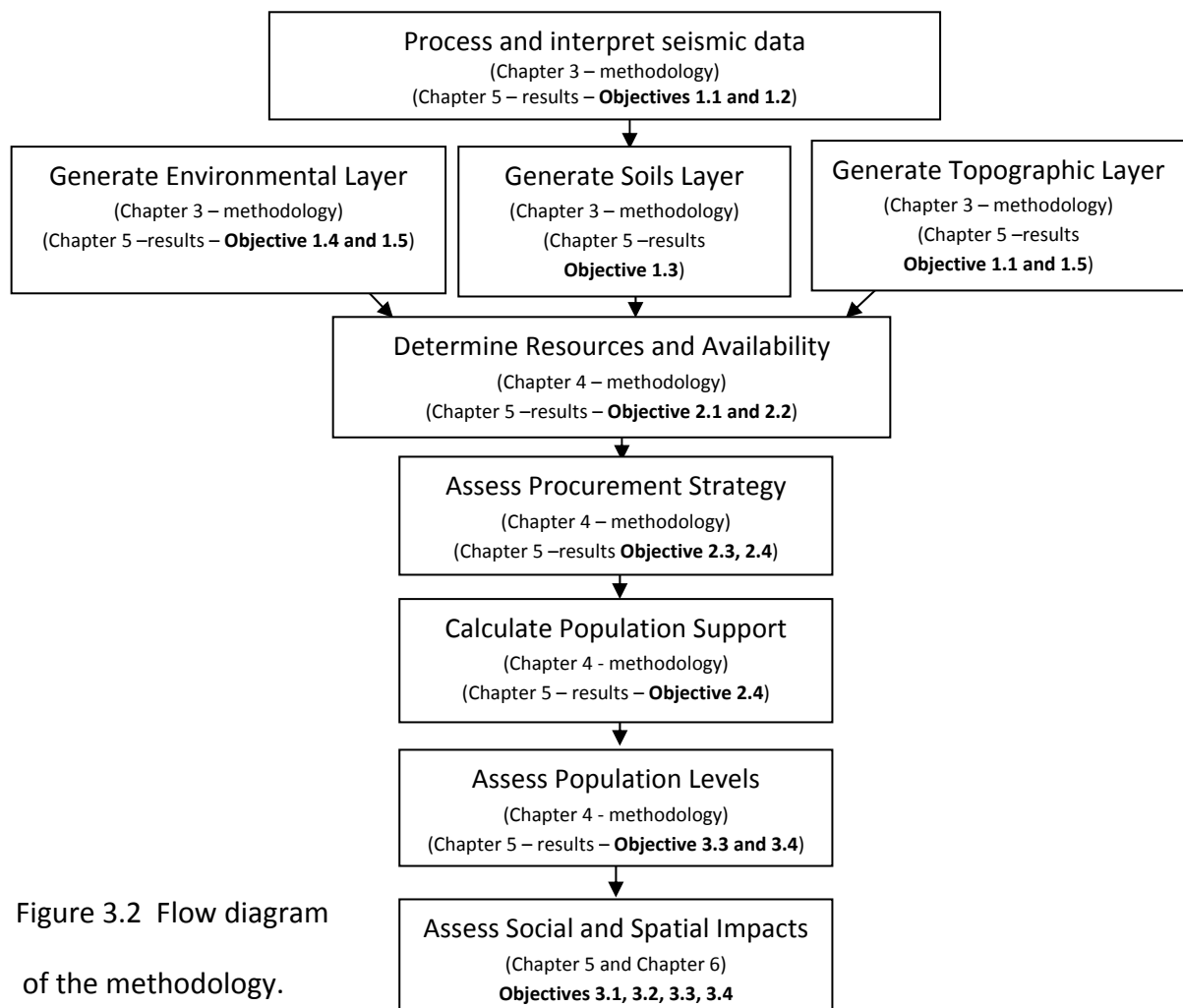
Figure 3.2 Flow diagram of the methodology.

3.5.1 Methodology: Description of 3D seismic data and its acquisition

Seismic reflection surveying involves introducing energy in the form of acoustic waves into the ground and recording the energy reflected from geological variation. This records the acoustic impendence contrasts within the earth, which are predominantly located at lithological boundaries. With suitable processing this data can be utilised for the generation of pseudo-cross sections. In these sections the vertical axis represents the two-way travel time to the reflector. The reflections are primarily the product of changes in lithology with the impendence contrast, or reflection coefficient (the ratio of how much energy (amplitude) is returned), given by the equation:

$R = (\rho_2 V_2 - \rho_1 V_1)/ (\rho_2 V_2 + \rho_1 V_1)$

Where:　　　R = reflection coefficient

　　　　　ρ_1 = density of medium 1

　　　　　ρ_2 = density of medium 2

　　　　　V_1 = velocity of medium 1

　　　　　V_2 = velocity of medium 2

Although the basic technique is common, there are various detail changes that are required for a number of applications, including the investigation of hydrocarbon resources (Bally, 1987) and near seabed sediment structure (e.g. Salomonsen and Jensen, 1994; Velegrakis and Dix, 1999; Praeg, 2003 and Bulat, 2005). These applications dictate different parameters during acquisition that in turn determine the resolution and depth of penetration of the survey. Consequently, the relative merits of a range of available seismic

reflection data types needs to be assessed when considering the investigation of

submerged, and partially buried, Holocene features.

Standard marine acquisition involves towing an energy source (usually an airgun) and a

cable (streamer) containing geophones that record the reflections from the underlying

geology (Figure 3.3). In single fold data, only one reflection is received from any point

below the surface. However, in order to increase the signal-to-noise ratio of the seismic

profile, many seismic profiles are multi-fold. This allows the reflections to be summed,

producing a clearer image. In addition, the character of the seismic source is intimately tied

to the required resolution and depth of penetration. As the vertical resolution is

dependent upon the wavelength produced by the source, it is therefore dependent on the

velocity of the medium and the frequency of the seismic source/reflected wave. Ideally, a

high frequency source (>100Hz) would be used in all circumstances. However, as the

geology progressively dampens high frequency seismic signals at depth, the seismic source

needs to be selected with a consideration of the required depth of penetration. The

dampening effect of the top few hundred metres of sediment is relatively small and

therefore seismic sources with frequencies in excess of 100Hz can be utilised. In contrast,

2D and 3D seismic data acquired for hydrocarbon exploration is required to image

geological features that can be several kilometres deep. Consequently, the seismic sources

employed generally have a frequency of less than 100Hz. This situation results in a higher

vertical resolution for 2D seismic data which is acquired specifically for the investigation of

shallow geological structures (<500m) as compared to standard 2D or 3D seismic data

required for hydrocarbon exploration.
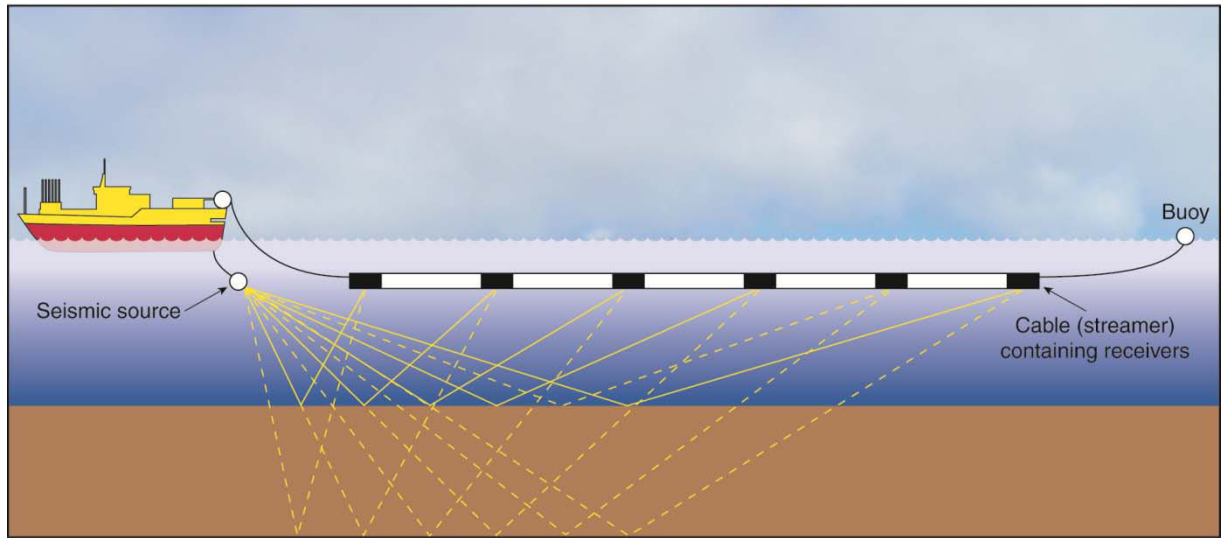
Figure 3.3 Typical marine seismic reflection acquisition. (Gaffney *et al.* 2009).

Traditional seismic reflection data is often referred to as 2D because of its acquisition as a

series of discrete vertical lines using a single streamer towed behind the boat. This pattern

of acquisition results in the collection of a number of profiles with a horizontal spacing that

is several orders of magnitude greater than the horizontal spacing along the profile. This

method of acquisition has two main disadvantages. Firstly, it is assumed that the reflected

energy originates from a point directly beneath the line. However, the possibility exists

that the reflected energy could have originated from a point laterally offset from the line.

Secondly, the line spacing can be sufficiently wide that it results in a situation where it is

difficult to map the position of a feature across the area of interest. For example, Figure 3.4

demonstrates how wide line spacing can lead to several equally valid interpretations.
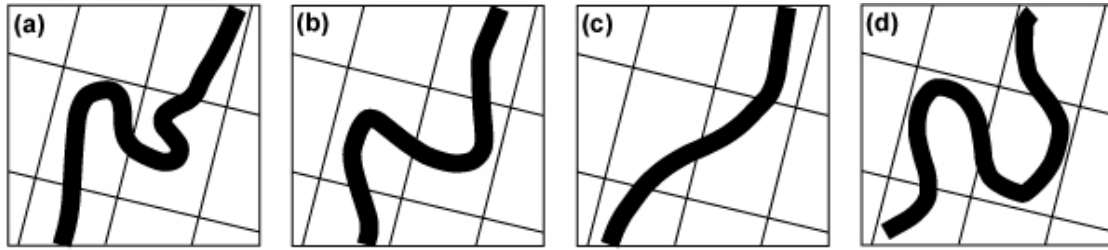
Figure 3.4 (a-d) Four possible interpretations of a channel morphology based on a coarse 2D seismic grid (from Gaffney et al 2007).   Each interpretation is equally valid, however the morphological differences between interpretations is significant enough to greatly affect the landscape interpretation, even though it is based upon the same data. Thus further information is required to resolve this issue.
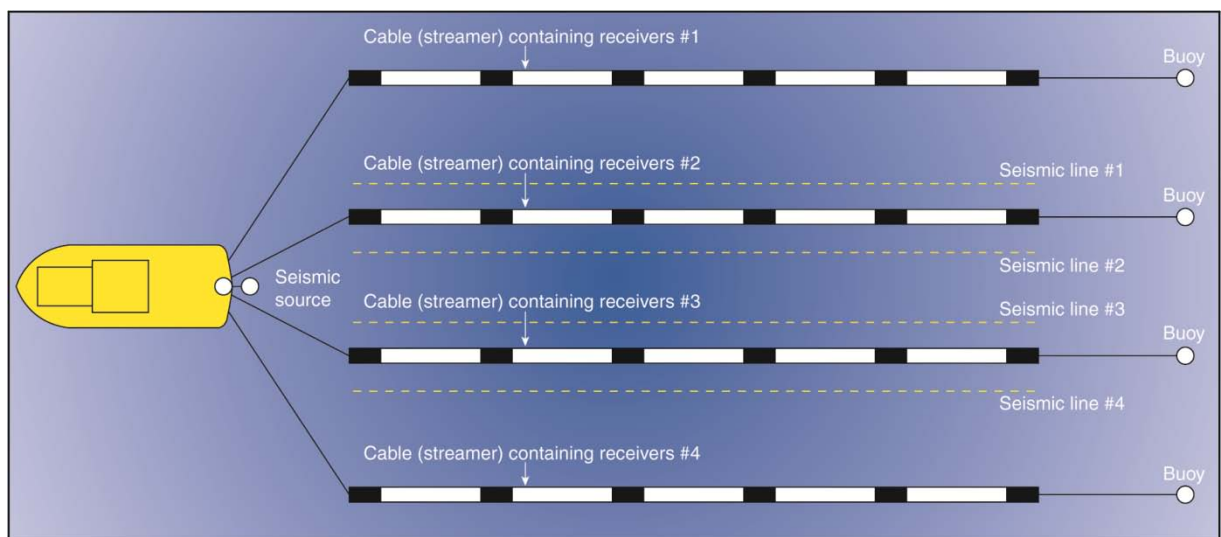
Figure 3.5 Typical 3D marine seismic reflection acquisition (from Gaffney et al 2007).

In contrast, 3D reflection seismic data involves the towing of a number of streamers as a series of closely spaced lines (Figure 3.5). This survey configuration offers significant advantages. It allows the seismic response to be correctly positioned in 3D space. The data acquired for can then be "binned" within the data volume. Commonly 3D seismic data is binned to a resolution of 12.5m x 12.5m x 4 milliseconds, or multiples thereof. Once

treated in this way a geological feature can be followed from bin to bin, thus removing the errors inherent in the interpretation of 2D data. Moreover, instead of relying on single vertical profiles, the volume can be visualised in any direction. This ability is of particular importance to the investigation of Holocene features, where their relatively shallow morphology is more suited to visulisation through horizontal slices (timeslice). In many cases, these timeslices can be interpreted in a similar fashion to an aerial photograph. 3D seismic data acquired for the hydrocarbon industry can generally be thought of as low resolution data when compared to traditional 2D seismic approaches used for shallow sediments. However, it can be demonstrated that 3D seismic data as used in this thesis, has the required resolution for near-surface investigation.

The resolution of 3D seismic data can be divided into two parts, vertical and lateral, both of which determine how close two points can be in space, but still be distinguished as individual features. The seismic data's resolvable vertical limit is defined by Widness (1982). This is defined as one quarter of the dominant wavelength (1/4 λ), and is a function of the seismic velocity and frequency content of the seismic data. Yilmaz (1987) also notes that this is often too stringent, especially in situations where the noise level is favourable. Where this occurs the amplitudes of events can be picked with ease even below this 1/4 λ boundary at levels approaching 1/8 λ (Yilmaz 1987). During acquisition seismic data is generated and processed to produce as wide a range of frequencies as possible. Therefore it becomes possible that in some cases it is the highest frequencies within a survey that constrain the limits of vertical resolution (Emery and Myers, 1996).

The frequency spectra for the seismic dataset provided for this study has 98.9% of the frequency content in the 3-60Hz range with a mean frequency of 14.7Hz. Consequently, a mean frequency of 14.7Hz provides a vertical resolution approximately 22m for the seabed when used with a seismic velocity of 1550m/s (typical of seabed sediment, e.g. Shumway 1960, Schock 2004). However a significant high frequency component remains, which suggests that a better vertical resolution is achievable. Using a value of twice the dominant frequency (35Hz) to take into include this high frequency content; the frequency value provides a maximum vertical resolution 10 metres. This, therefore, may be the most reasonable figure considering the frequency range and the amount of high frequency content within the dataset. The remaining high frequency content suggests that this too may be an underestimate, and that a vertical resolution approaching 6m may be achieved (see figure 3.6).
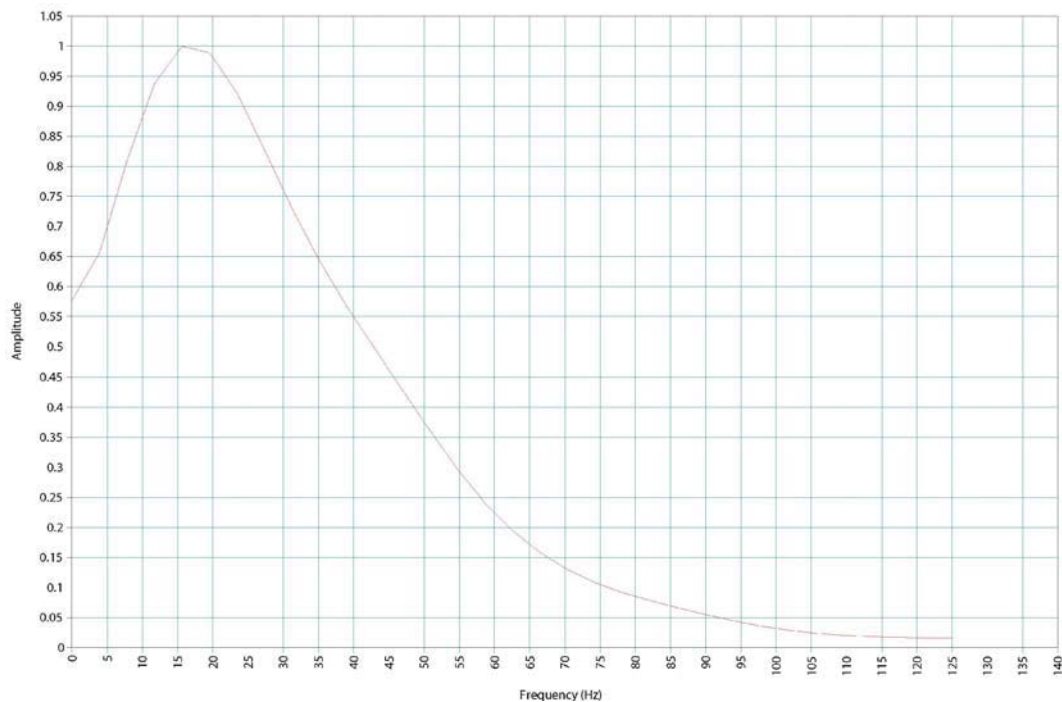
Figure 3.6: Graph of the frequency spectra from the 3D seismic data.

These observations agree with work undertaken by Steffens *et al.* (2004, 35) who notes that the near-seafloor section within conventional 3D seismic data often contains the higher frequency content (60 to 70Hz) that will yield resolutions of between 6 to 8 metres. As a result the dataset permits the mapping of the near seabed features with a resolution that is acceptable for landscape archaeological purposes. The limits placed on horizontal resolution of the unmigrated seismic data can be defined by using the Fresnel Zone (Sherrif, 1977). This is defined as the region on the reflector where seismic energy is reflected constructively (Sherrif, 1977). The width of this zone is dependent on the frequency content of the seismic data, the interval velocity of the signal and the travel time to the reflector. For the study area a two-way time range of between 170-410ms, the mean frequency of 17.9Hz provides a Freznel Zone of 7m. If we consider the acquisition perameters of the survey, however, it is likely that the line spacing of 12.5m is the actual limit. This 12.5m horizontal resolution means that the mapping of lithological information can be performed horizontally at an identical accuracy to that of the vertical component.

3.5.2 Methodology: Techniques of derivation of information from Seismic data

The study utilised SMT Kingdom 8.1 (32bit). Kingdom is a seismic geophysical interpretation package with spatial mapping capabilities. This facilitates the export of interpreted landscape data from the geophysical data directly into GIS. Kingdom also possesses the ability to import and integrate GIS layers within the interpretation, thus facilitating data validation and cross verification.

The technique of timeslicing is often regarded as the first step in a 3D interpretation of seismic data, and is achieved by dividing the 3D seismic data volume into a series of horizontal slices of equal time. In this thesis the 3D data volume was sliced into a series of slices at 0.004s intervals, from the start point 0.06s (where the first post seabed multiple was imaged), to 0.20s, where clearly resolvable glacial features appeared. The seabed was poorly resolved in the northern part of the study area, and so in this region multiples were used in the time slicing to gain a full understanding of the features at or near the seabed (Fitch et al 2005). The approach provided clear images of the depositional features, but the thin Holocene cover in this region (Cameron 1992) limited vertical, and hence temporal, separation of features. This resulted in depositional systems being interpreted in timeslices rather than vertical profiles, due to their morphology being better displayed. Indeed, during this research it became clear that that most of the fluvial systems in this area would have been missed if only vertical sections derived for the 3D seismic data or pure 2D sections were exclusively used.

In order to enhance the features seen in the time slices, several industry standard techniques were employed to improve the visualisation and interpretation. The first of these techniques, demonstrated, for example, by Kidd (1999), is opacity rendering. This technique converts conventional 3D seismic data into a voxel volume, with each voxel containing the information from the original portion of the 3D seismic volume it represents together with an additional (user-defined) variable that controls its opacity. The opacity of individual voxels can therefore be varied as a function of any of their seismic attributes, which thereby allows the user to explore only those voxels that fall within their particular

attribute range of interest (usually amplitude). This thesis uses opacity filtering in

conjunction with time slicing to image the depositional systems so that the fine detail of the

fluvial channel drainage patterns could be improved and resolved. This use of an opacity

filter is made possible due to the fact that the buried fluvial channels have lithological

characteristics that are different from the surrounding materials. This difference makes it

possible, within the seismic interpretation package, to make the surrounding rock

transparent whilst rendering all but the smallest channels opaque. This method therefore

permitted a clearer interpretation, and thus allowed a relative dating of the observed

structures to be performed.

The other main mode of visualisation within this thesis is RMS (root mean squared) time

slicing. This method is similar to that of time slicing, producing a map view image from the

3D seismic data volume. However, the method utilises the root mean square of the

amplitude within a section of the seismic volume located between two selected time slices.

The resultant data is shown as a slice which shows areas of anomalous seismic amplitudes,

and as the amplitude of the seismic data is often a function of density, this can aid

geomorphological analysis. In this thesis RMS slices were found to be useful in imaging

channels in areas of poorer resolution data, as well as aiding the clear imaging of deeper

structures (see Figure 3.7).

Seismic attributes can also be useful to visualise the data. A seismic attribute is commonly

defined as, "all the information that can be obtained from seismic data, either measured or

computed and include the amplitude, frequency, coherency and acoustic impedance of the

seismic data, as well as others" (Yilmaz 1987). Attributes are divided into two distinct

classes, those of physical attributes and geometric attributes.

1. Physical Attributes are related to the change in responses which is caused by

   variations in lithology and other such physical properties (impedance etc.).

2. Geometric Attributes are responses to changes in structural and stratigraphic

   morphology of the sediments, and are thus spatial variations of physical attributes.

In this thesis, attributes were used to calculate a coherency cube for the entire 3D volume.

Coherency cube imaging uses the 3D seismic volume in conjunction with coherence

coefficient equations created by Bahorich & Farmer 1995 to generate an output that

portrays stratigraphic anomalies clearly on times slices (Chopra *et al.* 2002). This method

provides an estimate of coherence through the use of time cross correlation to provide an

estimate of the apparent dips of stratigraphic features with the seismic volume (Bahorich &

Farmer 1995). The generated Coherence Cube was subsequently time sliced to improve the

definition of the fluvial features (see Figure 3.8). A coherency cube allows the visualisation

of seismic discontinuities, because it calculates the similarity of local seismic trace sections,

thus it displays changes between sediments types. Other geological studies have used

coherency cubes, for example, Peyton *et al.* (1998) noted that the use of a coherency cube

allowed an "image of the edges of the valley and different stages of the valley fill well".

Peyton also concludes that this method made visible many fluvial valley features that were

previously unknown. Similar results using this method have been reported in a fluvio-

deltaic system in central Oklahoma by Suarez *et al.* 2008. Additionally, once a stratigraphic marker of interest has been identified, it can be mapped across the 3D seismic volume to produce a horizon that may have a geomorphological or chrono-stratigraphic value but, in some cases, the output can approximate the original land surface itself.
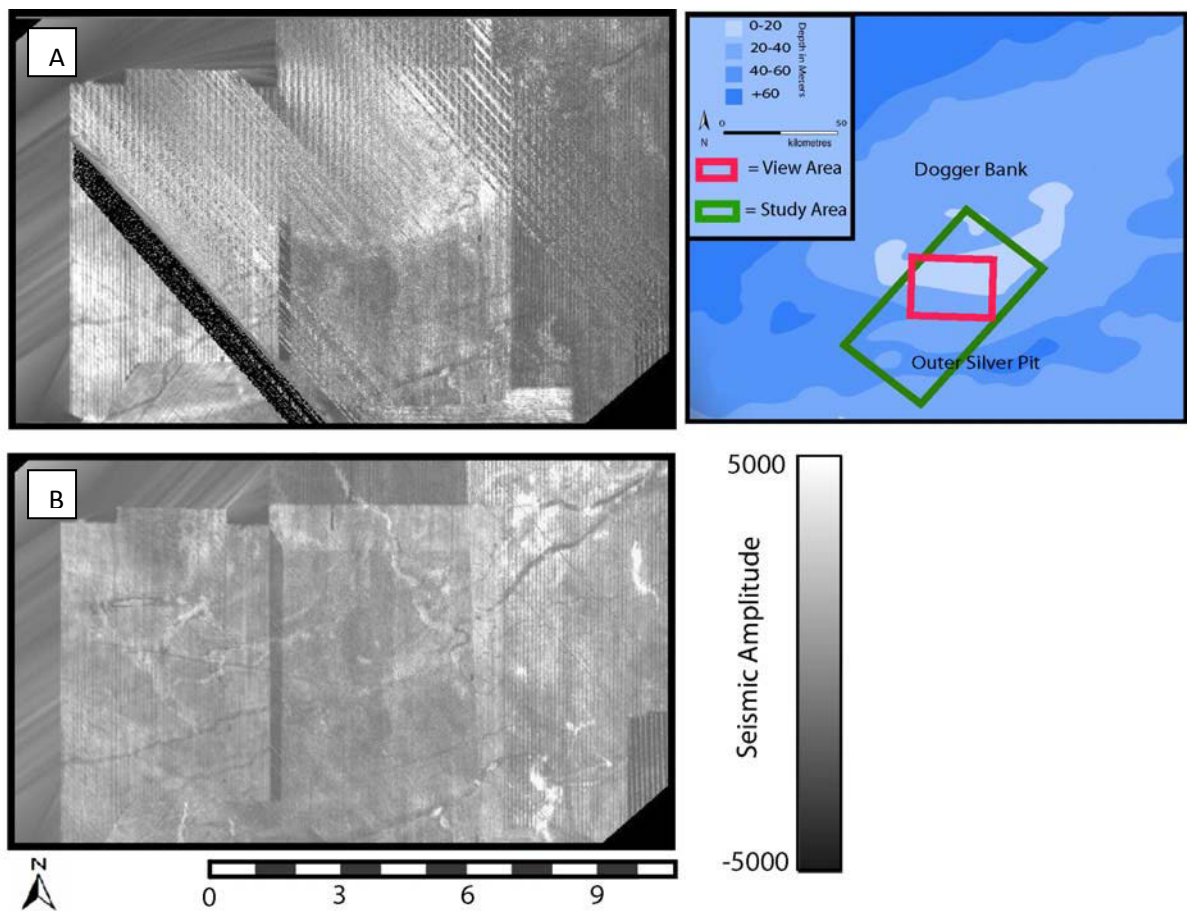
Figure 3.7 The value of RMS slices in areas of poorer data areas is apparent. A) is a timeslice near the seabed (0.052s), whilst B) is an RMS slice covering a similar time range (0.032s to 0.052s).
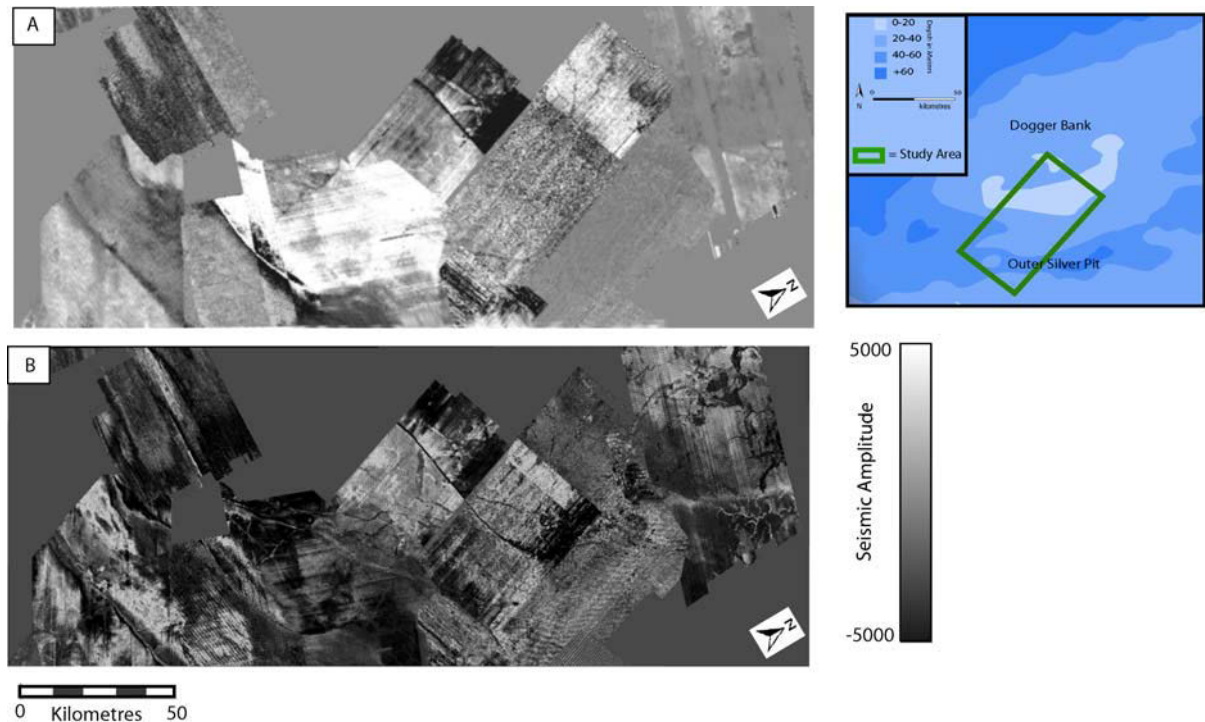
Figure 3.8 The value of a coherency cube in improving data clarity. Timeslice 'A' (0.076s) illustrates a slice through an amplitude volume, whilst Timeslice 'B' (0.076s) shows a slice through a coherency cube. It is apparent that time slice clarity is considerably improved through the utilisation of the coherency attribute.

The production of this stratigraphic information is useful, however further value can be gained by converting the seismic wave travel time into an actual depth. This method is known as depth conversion, and is regarded as an important step within seismic interpretation. A depth conversion integrates information from wells and empirical knowledge about the velocity characteristics of the subsurface to produce a model that can be utilized to provide depth information. The conversion is a strictly vertical correction and facilitates the production of depth maps from the interpreted seismic layers data. This method can therefore be used to convert an interpreted palaeo-land surface within the seismic data into a topographic map of the buried landscape.   At present whilst there are

93

two main methods to perform this conversion, there are multiple methods in existence, all of which have their benefits. These additional methods of conversion are rarely published in the literature (Etris *et al.* 2001), therefore this section will only briefly discuss the two main methods.

The first main method of depth conversion is Direct Depth-Time conversion. This method utilises well information to convert the time horizon information to a depth. This method disregards the structure of any velocity variations within the seismic dataset, and rather focuses on tying the seismic data to known velocity at wells (Etris *et al.* 2001). This results in the validity of the time-depth relationship being poorly known between wells, and therefore the confidence in the conversion decreases with distance from the well. However, this method offers the benefit of saving time by not having to produce a velocity model and guarantees that the seismic data ties exactly into the real world information provided by wells and cores. For the purposes of this research, this method's applicability is highly restricted given the limited core information available. Therefore this technique will not be applied.

The other method of producing a depth conversion is the use of velocity modelling. The goal of velocity modelling is the production of a model that describes all of the velocities of the units within the seismic data. This method generates a model that follows the layering scheme that most often follows lithological contrasts, rather than their actual geology. However in the case of shallow sediments this may follow the bathymetry as seismic velocity is often regarded as a function of depth of burial (Schultz 1999). Velocity models

can come in two main types, a single layer model, using a simple average velocity, and a

multi-layer model, which uses multiple velocities and considers the internal differences of

velocity within units (e.g. Van Dalfsen *et al.* 2006). The velocity data for the sediment layers

is derived from well data and/or from core samples taken along the seismic line (e.g. Schock

2004). Due to the time limitations present, a simple single layer approach was utilised. This

applies a single velocity for the area representing the water column within the data, and a

separate layer using a difference velocity for the sediment column. This data is then used

within the formula below for each layer to produce depth information.

Depth = ((WTxWV)+(STxSV))/2

Where: - WT= Water Time (seconds), WV = speed of sound in water,
         ST = Sediment Time (seconds), SV = speed of sound in sediment.

The resulting depth is divided by two as the input times are two way travel times (i.e. the
time it takes the acoustic wave to travel from the source to the reflector and return to the
receiver.)

3.5.3 Methodology: Assimilation of seismic interpretation into GIS

Timeslices can be automatically generated by most seismic interpretation packages.

However, there is little support for their export into other softwares, and other methods

must be employed to facilitate this. The export of planar data from a seismic interpretation

package is usually facilitated through horizon export. If a perfectly flat horizon is generated

within the interpretation package, and associated amplitude data is extracted, it can be

utilised as a pseudo timeslice, with identical properties to a timeslice. This pseudo slice

information is able to be exported to an external package in a range of formats suitable for

GIS import.

Through mathematical manipulation it becomes possible to generate a series of these

pseudo slices which can be utilised in a GIS in a similar manner to timeslices within an

interpretation package. With the generation of exportable slice information, a suitable

output format must be found. After careful consideration, it was considered that output as

a simple ASCII text file, in the format X,Y, attribute was the most appropriate given its

simplicity, transferability and non-proprietary format. With the generation of these ASCII

files it then becomes possible to reassemble this information into a format which is

viewable within a GIS as an image. To achieve this, ASCII files were processed using Erdas

Imagine 9.0. The modular surface extension was used to create an Imagine image based

upon the output text file. To achieve parity with the bin spacing of the seismic data

provided for this project (12.5x12.5 metres), an output image with a similar cell size with

32bit data attributes was utilised.

This format was chosen to keep both the output image size manageable, but also to retain a high level of detail. It must be noted that this is an extremely time consuming task, even on a Compaq w8000 workstation with two dual thread processors (@2.0GHz) and 4GB of RAM, the generation of a slice for one survey block with such a large amount of information could take a minimum of 48 hours. Given the time taken by these processes this task was automated over weekends because of the disruption that such a computationally intensive process caused to the workflow. Once the image generation process has been completed, the result is a standard Erdas .IMG file which is compatible with many GIS systems. This style of processing retained the data set's high degree of geographical accuracy, and eliminated problematic processes such as rectification, which would have been necessary in other timeslice export processes. The generated slice information therefore provides the basis from which a more traditional series of GIS interpretation layers can be generated. The interpretation was performed through on screen digitisation and assimilated into a variety of cogent data files which were combined to show the full extent of the information acquired by the survey.

3.5.4 Methodology: Geographical Information System - landscape interpretation of data

The bulk of the GIS analysis was performed within ESRI's ArcGIS 9.1 (a discussion of GIS can be found in Chapman 2006). The planar nature of the geophysical surveys facilitates their easy integration into a traditional GIS's map style representation. However, the presentation of a true three dimensional volume of geophysical data, which 3D seismic data represents, is a challenge especially when considering its representation within a planar GIS

system (Kvamme, 2006). Improvements are possible within certain GIS viewers which allow for the integration of a third dimension, for example ESRI's ArcScene extension. But whilst the application allows for a full three dimensional representation of objects within a GIS, the representation of these objects consists of purely planar surfaces. Currently, therefore, these systems are unable to adequately display a volumetric representation of a cube of data, which 3D seismic data represents.

However, given the invaluable ability of GIS to rapidly interrogate multiple disparate datasets and display this information upon a common display, it is clear that integration of data derived from seismic survey within a GIS environment would be both desirable and profitable. Indeed, this integration would ultimately lead to improved archaeological interpretations and facilitate reliable archaeological predictions. The challenge, therefore, is to integrate this interpretation data into a planar system whilst retaining the integrity of the derived information.

3.6   Integration of information

Given the limitations imposed by the GIS and its mode of representation, several techniques must be employed to facilitate the integration of these data within a standard system. A cube of seismic data can be seen as representing a series of planar time slices, whose nature is more appropriate for application within a GIS system. This ability would facilitate its interpretation alongside more traditional GIS layers.

Additional slices can be generated from cubes of attribute data generated from the seismic data cube to further assist interpretation. It would, however, be undesirable to introduce all the possible time slices within the GIS, indeed, depending on the number of attributes used this could number in the thousands. This would add unnecessary complexity and vastly increase the amount of data to be manipulated beyond that which is currently realistic within the computing capability of a GIS and perceivable by the operator (Kvamme 2006). Therefore, a selection of slices derived from the most commonly used data attribute, that of amplitude, were chosen to provide information into the GIS. This selection however does leave the possibility that information may be missing from between these slices. To compensate for this RMS (root mean squared) slice technology was used to allow for some of the missing volume information to be represented as a 2D slice.

It was decided that a suite of polyline features would be most suitable to represent linear features. A polyline is a GIS feature which is constructed of a continual line of linear segments; this nature makes them ideal to represent linear features within a GIS system. These polylines were used to record the presence of observable large solid geological boundaries (at or near the sea bed surface), along with observable geological faults (also near surface) and modern sand waves. These features, whilst not directly holding any immediate archaeological significance, were recorded to aid future researchers distinguish such features within a GIS. Simpler display characteristics also facilitated easy comparison to available geological and sediment mapping for the region. For similar reasons the linear shorelines observed in the south of the study area, which are associated with the early

Holocene marine transgression of the region were also recorded as polylines in a separate file.

Once these basic polygons had been generated it was important to provide a discreet polygon layer for features of the Mesolithic landscape of this region to support archaeological analysis. Features which were observed to be part of the terminal Pleistocene and Early Holocene landscape were compiled into one cogent suite of polygons. The observed temporal succession of features was recorded as a discrete attribute of each polygon. Upon the generation of this data layer, any features which could be joined on the basis of their spatial and temporal morphology were assimilated into a single polygon. This process was performed and expressed as a separate interpreted data set, so as to allow future research to directly observe the effects of the joins made. Once the join was completed, centrelines for each feature could be generated as a polyline to facilitate the investigation of the fluvial feature attributes.

To acquire topographic information from the seismic data, a seismic pick was performed to produce a surface. A seismic pick is a selection of a feature or layer from the seismic dataset by an interpreter. The pick data often corresponds to geological or sedimentalogical units and thus can be used to represent palaeo-land surfaces. The topographic data acquired from the pick of the palaeo-land surface in the seismic data was then converted to depth using a multiplication with the seismic velocity of seawater (1500 m/s - Bertrand *et al.* 2003) for the area above the seabed, and a velocity of soft sediment (1550 m/s - Schock 2004) for the area below the seabed. This was utilised to compensate for the differences in

seismic velocity in sediment as opposed to water. The generated topographic data was used instead of using the local bathymetry as a proxy for Palaeolandscape in this area as observations with the Gauss 2D seismic data reveal that the landsurface in this area is buried at depth (see Fitch *et al.* 2005). This surface was then smoothed to help reduce the effect of acquisition lines, which are a product of data acquisition (Loader C. pers. com). From the resultant points a grid representing the topography was generated within the GIS. To this grid was applied Shennan's (2002) sea-level curve for this region. This was applied to the data as a series of layers representing sea level (expressed as a depth) at 500 year time intervals through the period 10,000BP to 7,500BP. This consideration of sealevel facilitated a consideration of the topographic changes brought about through sea level rise.

3.7 Classification of the fluvial features

To assist in understanding the fluvial systems and their importance within an archaeological landscape, a classification of the fluvial features was sought. For the classification of rivers, centre lines were first generated using a series of attributes calculated by the ArcGIS 9 extension 'RivEX' (version 3.10). RivEX is a vector river network tool, that utilises an recursive algorithm pioneered by Gleyzer *et al.* (2004), that allow for the computation of Strahler stream order values within a vector GIS.

For the purposes of this thesis the following attributes were generated and attached to the ArcGIS polylines.

- Strahler order

- Shreve order (for non-braided systems)

- Catchment ID

3.7.1 Strahler Stream Ordering

The Strahler system of ordering for stream sizes is a simple algorithm based upon stream hierarchies, proposed by A. Strahler (1952) and can be considered similar to Horton's ordering system of 1945. This process works by ordering all of the headwater (unbranching) streams as a value of 1, or first order. When two first order streams converge, the resultant stream is described as second order to generate a third order stream, a convergence of two second order streams is required. The system requires that if any tributary of a lower order joins that of a higher order channel, it is ignores, for example, if a second order and a first order stream converge, the resultant stream is still second order (see Figure 3.9a).

3.7.2 Shreve Stream Ordering

The other commonly used hydrological ordering system that was applied included Shreve's (1967) system. This designates all un-branched streams as first order, and that any joins between two streams causes the orders to be added. This results in two first order streams producing a second order stream, whilst the joining of a second and a first order stream will produce a third order stream (see Figure 3.9b). This additional nature of the stream orders

is distinctly unlike that of the Strahler system and can result in very high stream orders being generated. To facilitate the accurate calculation of the stream attributes the centre lines of systems that were in close proximity to each other and had good evidence for linkage, both temporally and spatially, had their polylines joined to create a more complete river network. The generated attribute values were then automatically recorded in the attributes table.

In areas where a braided system was observed, the longest route was chosen by RivEX to calculate an order for that system, assigning all other branches the value of zero. It must be noted that since the features recorded are river valley floodplains the Strahler and Shreve orders produced by this technique are the minimum order of the fluvial feature. As both ordering systems are highly dependent on map scale, it is therefore likely that the stream orders of these features are probably of a greater stream order than represented, however, the broad relationships between the observed features and their systems are likely to be consistent. These stream order values do however provide a reasonable basis upon which the fluvial features can be classified and understood.
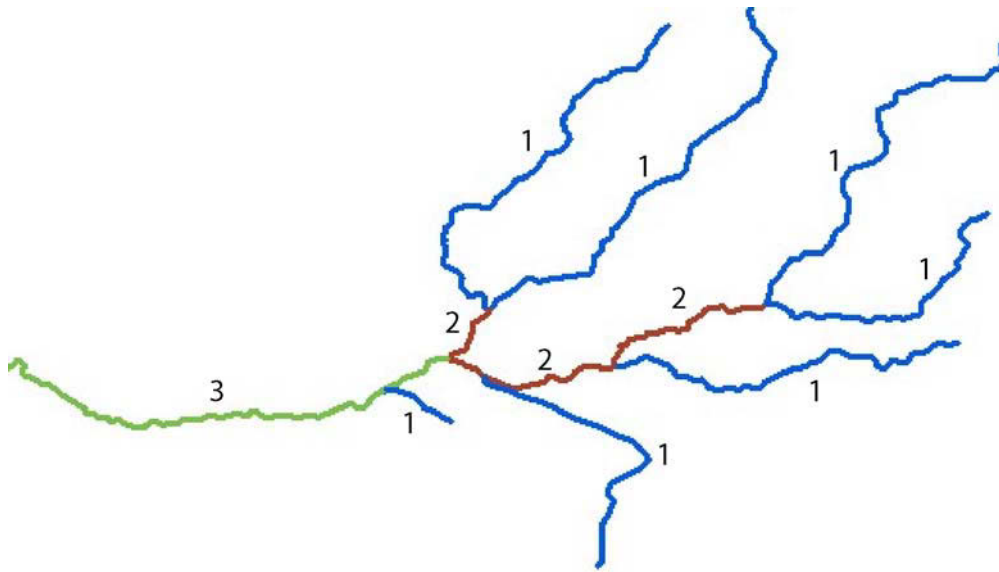
Figure 3.9a Example of Strahler stream ordering. A higher stream order is only achieved when two streams of similar order meet. When two streams of different order confluence, the order remains that of the highest stream order at the confluence. In this example the maximum stream order reached is 3rd order (coloured green).
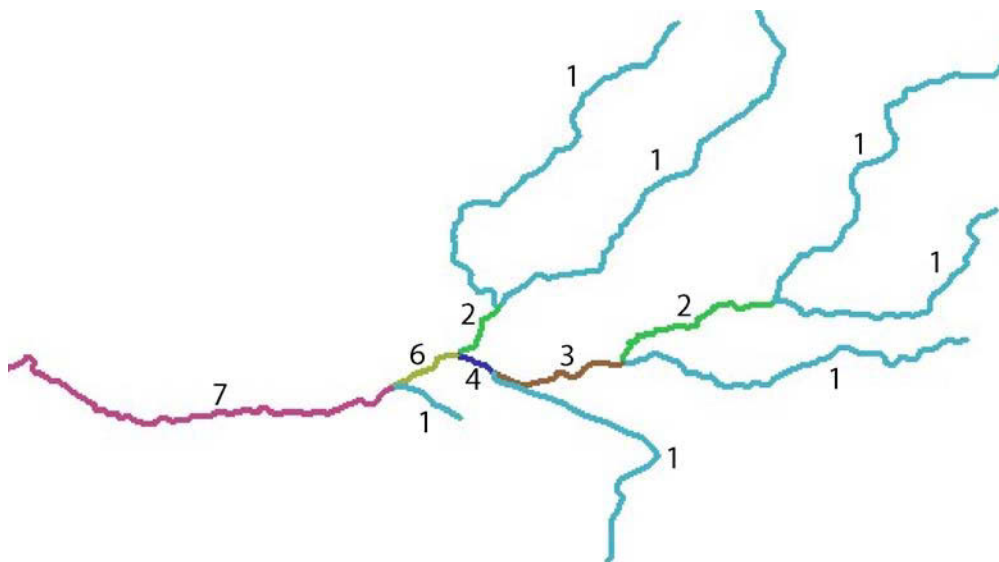
Figure 3.9b Example of Shreve stream ordering. It is important to note that when streams converge, the ordering process is summative. In this example the river achieves 7th order (coloured pink).

3.7.3 River Classification

To provide further information in the GIS system about the nature and morphology of the rivers, the sinuosity of each system was determined utilising the formula derived for this purpose by Leopold *et al.* (1964) (see Figure 3.10) using the river centre line data. A range of sinuosity figures would then be obtained for the regions fluvial systems. It must be observed, however, that the sinuosity of these systems generated by this method is expressed as a minimum figure. This is will be a more apparent phenomena for the project since most of the fluvial features imaged by the seismic data are in fact the floodplains. It is therefore extremely likely that the actual sinuosity figures for the rivers contained within these floodplains could be higher than the ascribed value.
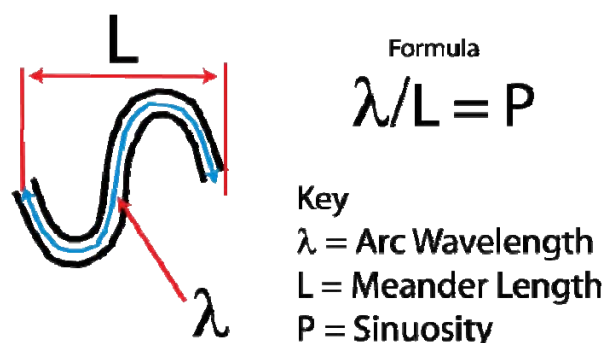
Figure 3.10 Calculation of Sinuosity, after Leopold *et al.* (1964).

The resultant channel data on sinuousity was then classified using Rosgen's (1994) classification table (see Figure 3.11). The caveats observed for the sinuosity still apply, because of the use of minimum figures. It is very important to note that older features in this area which had a longer time to evolve a complex floodplain system, would express a

high sinuosity. Conversely, relatively new fluvial systems would have little time to generate

a floodplain system and thus would express a lower sinuosity. A combination of both

results was produced for this study.

Dominant slope range	Aa+ >10%	A 4-10%	B 2-4%	C <2%	D <4%	DA <0.5%	E <2%	F <2%	G 2-4%
Cross-section									
Plan View									
Stream Types	Aa+	A	B	C	D	DA	E	F	G
SIN.	< 1.2		> 1.2	> 1.4	< 1.1	1.1-1.6	> 1.5	> 1.4	> 1.2
W/D	< 12		> 12	> 12	> 40	< 40	< 12	> 12	< 12
SLOPE (degrees)	.04-.099		.02-.039	< .02	< .02	< .005	< .02	< .02	.02-.039
	Straight		Low sinuosity	Meandering	Braided	Anasto-mosed	Stable Meandering	Entrenched Meandering	Gullies

Flood-prone area - - - - -
Bankfull stage ———
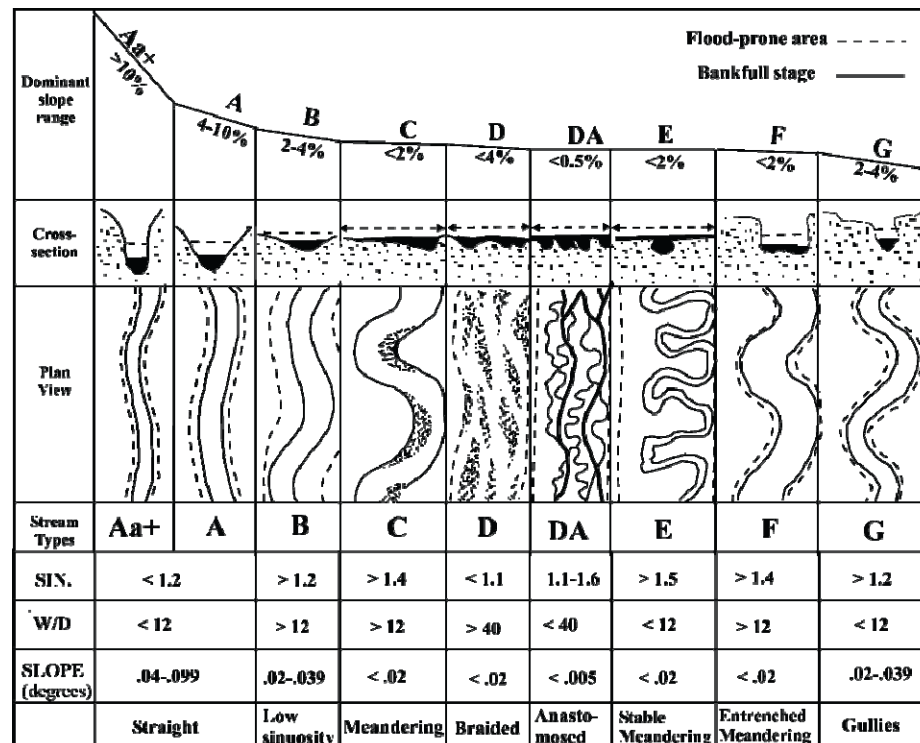
Figure 3.11 Classification of Rivers, after Rosgen (1994).

3.8 Generation of a soil map

Due to the submergence and burial of the Mesolithic landscape of the southern North Sea,

there is a significant lack of soil information that could be used for archaeological modelling

purposes. A simple reaction to the lack of soil information would be to reclassify the

existing geology maps for the region. This, however, would be a gross over-simplification

due to the nature of the evidence utilised to produce the geological mapping of the region.

It is apparent from the visualisation within the 3D seismic data that whilst the bulk of the

106

classification and location of strata are relatively correct, many of the important boundaries on the maps are not located in a highly accurate manner. This is not a direct criticism of the mapping, rather an acknowledgement that they were never intended for use at high resolutions.

To the best of the knowledge of the author there are no known soil samples (excluding peat) that have been recovered directly from the North Sea. Thus, there is no direct physical evidence that could be utilised to assist in the production of a soil map. Given the and lack of information, soil data must be derived using other means. Although the seismic data can provide accurate spatial evidence and possible parent material, it is not able to provide all the information required. Soil formation in this region can be expressed as a function of several factors. The most significant of these are climate, parent material and biotic action.

3.8.1 Controlling factors

The climate of an environment during the soil formation process can be critical. For example at temperatures of below 0 degree centigrade will stop all biological and many chemical processes and thus soil formation is then primarily a result of mechanical action (frost action, freeze-thaw etc.. Strahler and Strahler 2000). However, in slightly warmer climes between 0 and 5 degrees centigrade, root action from plants is possible (although limited) and chemical reactions between soil water and the parent material are possible (Strahler and Strahler 2000). From this, it can be seen that climate is the engine that drives

soil formation, due to its provision of moisture for the weathering of parent material, and in colder climates encouraging physical break-up of the parent material.

The actual parent material of the soil also has a major effect on the soil type. Since the soil will derive it mineral and a fair degree of its nutrient content from this material. Composition and ease of weathering will greatly affect the fertility of the soil. For example, a soil derived from granite is likely to be poor and thin, due to the granites slow rate of weathering and the nature of the chemical weathering of the rock, which produces silica and clay minerals and result in few nutrients (Gill 1997). A mudstone for example is more susceptible to weathering, and chemical attack, which produces nutrients. Thus, it is clear that the physical nature and chemical composition of the parent material greatly controls the speed of its physical and chemical weathering as well as the derived nutrients which are inherited by the soil.

Further to this, biotic action in the form of roots has a profound impact on the soil. Indeed, it can be seen that in a new available area, such as the southern North Sea during the Holocene, the evolution of the soil can be observed to strongly correlate with the vegetative succession in the region. This is due to the changes imposed on the soil by vegetation, which physically breaks the parent material and releases acid (H+ ions) into the soil water to allow the absorption of nutrient ions. This release of acid speeds chemical weathering, which can be further assisted through the presence of organic material added to the soil.

3.8.2 Generation of the soil map

Given these factors, the production of a soil map for this region could be extremely complex. However, it is fortunate for the study that all of the lithologies in the southern North Sea have a strong correspondence to similar units found in Northern England. It is therefore possible to correlate parent materials and thus soil type for several regions. For example, the boulder clay found in the north of England is observed by Cameron (1992) and Scourse et al (1999) to be very similar to parts of the Dogger Bank/Boulders Bank formations of the southern North Sea. Thus, as the material in Northern England produces a gleyed basic soil, it is reasonable to assume that a similar soil evolution was followed on the areas which derived their source parent material from the Dogger Bank formation. Other parent materials found in the southern North Sea, such as chalk, have strong and well known parallels in the UK. Thus such correlations can be of great benefit evaluating the relationship between parent material and soil type.

Those parts of the Outer Silver Pit contained within the study area are more problematic and study of the soil conditions are complicated by the mode of formation of this depression. The timing of formation of this depression (Late Pleistocene vs. Early Holocene) has a strong effect upon the amount of weathering and hence soil type, in this area. This is further complicated by later marine erosion. However, to reduce the complexity to a scale which could be resolved within the timescale of this thesis the matching of soils to potential parent material was used as an approximation. It must be observed that the parent material, due to its glacial nature is likely to contain some local variations according to the material from which it is formed (Cameron *et al.* 1992). The bulk of this material is,

however, broadly similar and therefore any local effects are likely to have little impact on broader interpretation.

Using such correlations, it is possible to generate a soil type from a "near surface" (roughly the top 20 meters of seabed) geology map, as such a map was not available for this region from BGS mapping. This was generated from the available 3D seismic data. Through correlation and reference to the prevailing geological knowledge of this region, outlined in Chapter 1, it was possible to derive the required parent material information required for the generation of the soil layer. This information was re-classified within the GIS to produce a soil map.

3.9   Environmental Model Phase –Tree colonisation data

With the generation of soil type information, it is now possible to consider the potential tree cover of this region. The seismic data and soil maps outline a number of potential landscape features preserved in the seabed around the Dogger Bank. These are likely to include features such as large river systems, low lying hills etc. Although the southern North Sea lacks clear pollen data, archaeology has familiarity with these types of environments. Consequently, it may be possible to use the current prevailing environmental information from the terrestrial sphere to gain an understanding of the tree cover of the landscape.

More than 70 years of pollen analysis from sedimentary profiles, dating back to the work of Godwin, allows a picture of environment in the Mesolithic period in the British Isles and on

the eastern reaches of the North Sea to be constructed (Godwin 1975, Huntley and Birks 1983). Unfortunately, as observed above and in Chapter 2, the local picture for the southern North Sea, and particularly the study area, is less complete. This is due, to the complications caused by the nature of the deposits of interest, which are often covered by several metres of seawater and overlying sediments. Despite this, there have been attempts to look at pollen from various blocks of material from the bed of the North Sea retrieved in fishing nets (Godwin 1943, Godwin and Godwin 1933). However, there remains a lack of suitable material for analysis from the study area. It is, therefore, important that the available information from the terrestrial sphere is utilised to produce data suitable for input into the GIS and model.

Utilising pollen isochron's generated by Birks' (1989) and the maps from Huntley and Birks (1983) (see Figure 1.7), it is possible to track the spread of trees through the region. Furthermore, as tree preferences for soil and plant competitiveness are well know and similar to the present day, it is possible to further constrain this data through the utilisation of the soil map. Therefore, the methodology initially utilised basic map digitisation methods within ArcGIS to convert Birks' (1989) maps to digital form. Once achieved, the generated soil and topography data (Sections 3.5 and 3.8) area were applied. Localised corrections were applied where necessary to take these factors into consideration. Additionally, Shennan's (2002) sea-level curve for this region was applied to facilitate a consideration of the available landscape and any physical barriers to tree spreading. The resultant data layer is shown in Figure 3.12
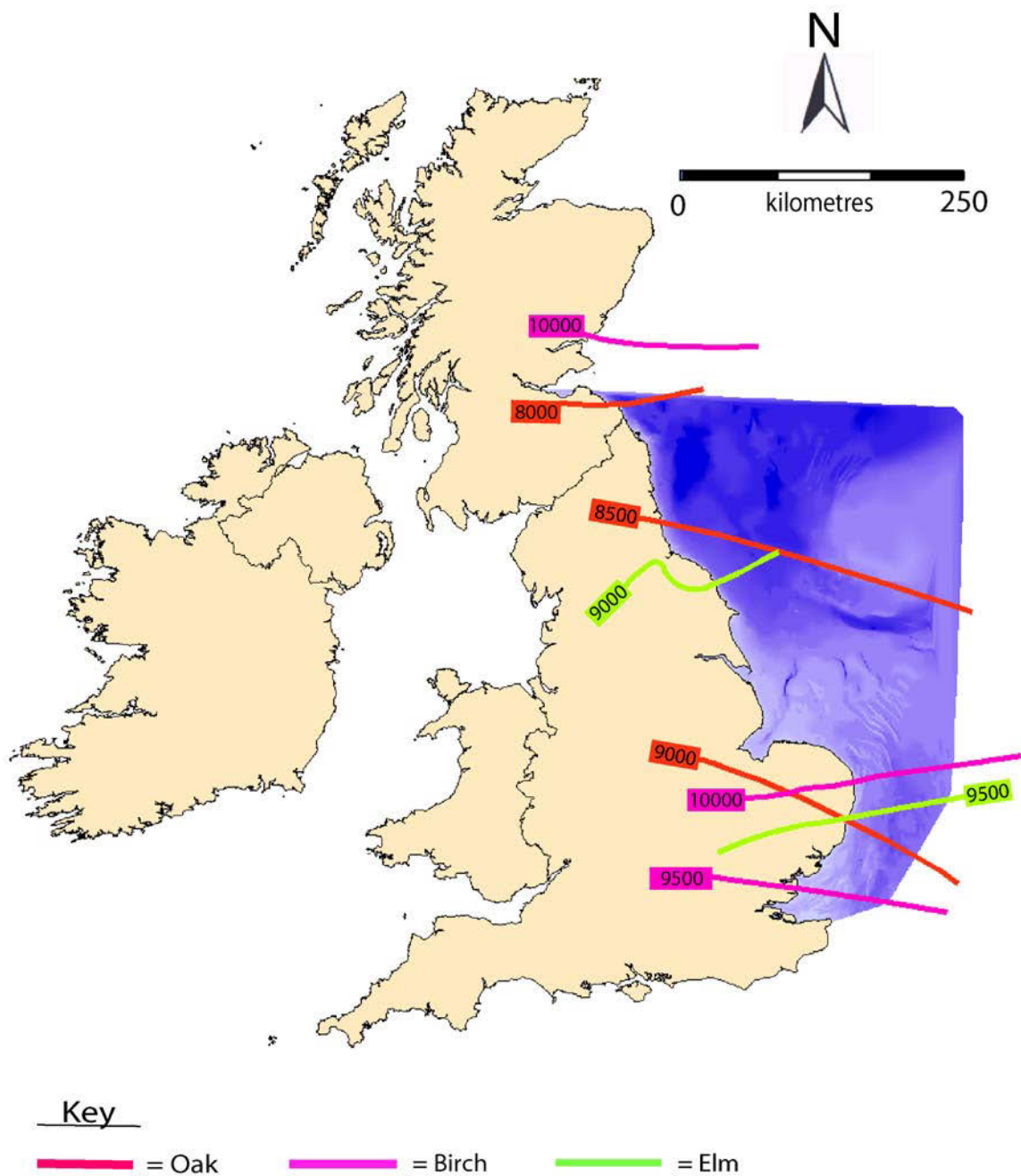
Figure 3.12 Pollen Isochron map (after Birks 1989) within the GIS. Each coloured line represents a specific species at a particular time period.

3.10 Synthesis

As observed in both Chapter 1 and 2 of this thesis, there has been a requirement for additional data in order to achieve the aims and objectives of this thesis due to the absence of base data for this region (see Chapter 1). By achieving the provision of this important base layer of information, it can be observed that this chapter directly addresses **Aim 1** of the thesis, specifically "To generate physical landscape data and environmental change across it".

It is important to observe that this methodology provides an important data for the region which was previously not available. This thesis' utilisation of a methodology of using 3D seismic information in conjunction with other datasets has been successful, thus allowing the resolution of:

Objective 1.1: To generate topographic data and identify topographic key features from 3D seismic data.

Objective 1.2: To identify key landscape features within the 3D seismic data.

Given the datasets available prior to this thesis, it is apparent that traditional methodologies would have produced insufficient to allow the production of an archaeological model. By providing a methodology to produce soil and tree colonisation mapping, both Objectives 1.3 and 1.4 will be met, specifically:

Objective 1.3: To generate a suitable soils dataset from the available mapping and 3D seismic data.

Objective 1.4: To generate mapping of tree colonisation of the study area over time

Additionally by achieving the above objectives the chapter succeeds in assisting the future resolution of the following objective, which will be achieved by applying a sea level curve to the resulting data:

Objective 1.5: To apply sea level curve data to the data generated by the above objectives (1.1 to 1.4) to simulate inundation.

Through the examination of the data, it will be possible to examine the subsistence patterns within the study area. As such the data will provide the foundations upon which the archaeological model can be constructed. In the next chapter the methodologies by which this will be achieved will be discussed and the progress towards **Aim 2** (create models of human resource use and population) is presented.

CHAPTER 4

METHODOLOGY: GENERATION OF MODELS

4.1   Introduction

The previous chapter outlined the methodologies applied for the generation of the past

physical landscape towards addressing Aim 1 of the project by establishing a baseline

model of the physical landscape of the study area during the Mesolithic. The purpose of this

chapter is to present the methodology that will be applied to the data generated by the

methods outlined in Chapter 3. As such, the methodology presented in this chapter will

therefore seek to address **Aim 2** (create models of human resource use and population) of

this thesis and provide data to assist in the achievement of **Aim 3.** More specifically, this

chapter will provide the methodology to allow **objectives 2.1, 2.2, 2.3** and **2.4** (see chapter

1) to be addressed.

Considerations of resource carrying capacity of landscapes have been investigated since the

1970s and have been further developed through the 1980's and 1990's (Jochim 1998).

Therefore this chapter will begin by briefly introducing the history behind Jochim's 1976

qualitative model, which will be utilised by this thesis, in part, for population determination.

Following from this, the history and development of some of the modelling techniques used

will be outlined. Once this has been achieved, the methodology to be utilised will be

outlined and detailed. Additionally, the thesis specific modifications to the formulae behind

Jochim's 1976 qualitative model will also be presented.

4.1.1 Introduction: Jochim's 1976 qualitative model

Several different styles of modelling have been utilised in the past to determine foraging behaviour, and ultimately population density within hunter gather societies. These primarily fall into two main groups, that of optimal foraging models (both linear and decision based), and qualitative models.

These models seek, in their own fashion, to determine efficiency of food procurement that, once determined, is utilised through the application of known dietary requirements to determine the supportable population size. However, the two groups of models utilise differential approaches to this determination, each with its own strengths and weaknesses. This short sub-section will briefly outline these approaches and then explain why a derivation of Jochim's qualitative model was applied in this thesis.

Optimal foraging models utilise optimal foraging theory (created by MacArthur and Pianka (1966) based on economic and ecological concepts) to attempt to produce a model of optimal subsistence for both human groups and their prey animals (Kamil *et al.* 1987). The linear programming, economic style of an optimal foraging model (e.g.Reidhead 1980) seeks a least cost solution to the issue of foraging and subsistence. The decision style of modelling (e.g. Mithen 1990) utilises the goal of achieving increasing foraging efficiency in determining the foraging strategy. Whilst the models differ slightly in the issue of strategy, all of these models attempt to measure the quantitative efficiency (both cost and benefit) of pursuing a particular resource. Both styles of modelling include the assumption that

116

humans, tend to exploit their prey resources in such a way that costs are minimised and benefits maximised. Additionally, they also assume that subsistence practices vary in their efficiency in terms of time and energy costs, and that increased efficiency results in increased fitness of the hunter.

The benefits of such methods include the ability to demonstrate the effects of specific economic variables upon the form of the population's subsistence (e.g. Mithen 1990). However, optimal foraging theory relies heavily on direct measures of cost and energy as well as technology utilised. Whilst this may seem desirable, there are serious issues with this. The requirement for direct measurement results in the models utilising recent subsistence data from modern foragers and the technology utilised during procurement. Given the impacts of modern societies upon almost all hunter gather groups, it is reasonable to question the applicability of such data. Optimal foraging theory has encountered further criticism over some of the assumptions that it makes. Martin (1983), for example, proposes that the assumption that foragers consciously optimise their strategy is confused, as the prey learns to avoid foragers or decline in density, and thus optimisation benefits would be relative. Furthermore, optimal foraging theory has been criticised by Yesner (1985) for not taking into account seasonality, with foraging occurring within a steady state/static environment. The failure of optimal foraging theory to include cultural phenomena, such as catch sharing, due to the individual nature of the benefit analysis, has lead to further criticism (Dwyer 1985). Ebert (2004, 14, 16) suggests that there is a real problem in applying optimal foraging theory within archaeology, due to the lack of exact knowledge of the potential resources available for foraging. Additionally, given the bias

inherent in the archaeological record, an accurate input of resource procurement technology data is problematic. Given these issues, quantitative precision within models should be questioned, as almost all of the inputs for any particular variable are estimates.

Jochim's 1976 model uses a slightly different approach by utilising qualitative measurements of prey weight, aggregation size and mobility to resolve the subsistence issue. As the model uses qualitative measurements, it does not seek absolute values, but, rather, seeks to display general relationships through ranking of resources and their efficiency. Developed by Jochim from ethnographic research and his studies in south western Germany, the model is based upon the ecology and resources of his study area. Jochim's model examined the factors that determine the exploitation of resources by hunter-gathers. These findings were used to generate a mathematical model which seasonally predicted the probable resource utilisation, as well as their effects on seasonal settlement. As such, the model relies upon indirect measurement of foraging practices and is much simpler in structure than most quantitative models.

Jochim divided the model into 3 modules, the "Resource use schedule", "Settlement location model" and the "Demographic model". The "Resource use schedule" module used two main ethnographic goals to govern the decisions of hunter-gathers, "*secure income of food* and *population aggregation at minimum cost"*. To define these goals, Jochim considered the weight, population density and mobility of the prey species, to produce a resource "score". Under this regime, a species of low individual weight, low population density and high mobility scored poorly.

To calculate the secure income of food Jochim (1976) used the following formula.

wnd/m

Where w = weight, n = Non food yields, d = population density and m = mobility

Population aggregation at minimum cost was calculated using this formula (Jochim 1976, 25):

wna/m

Where w = weight, n = Non food yields, a = aggregation size and m = mobility

The proportional score for each resource use was defined in the following formula for each goal, to determine the resource use strategy (Jochim 1976, 26).

Resource use % = resource score / sum of scores *100

For both goals Jochim defined this as:

Total resource use % = Sum of both resource use % / 2

Jochim proposed that this resource schedule model could be used to predict patterns of settlement location. The basic principle behind the module was that hunter gathers would be prepared to travel variable distances from a base camp to resources. This distance of travel is based according to the attractiveness of those resources to hunter gatherers. The location of each camp was then suggested on the basis of the resource distributions in those months' dietary values. Jochim then based the demographic model module upon this to assess the opportunity of people to aggregate based on the resources available.

This model has attracted criticisms. Mithen (1990), for example, states that prey aggregation sizes may be different in modern species, and that prey mobility (speed,

distance, frequency) is only presented as one measure. Other critics observe that the

model ignores prey size variation (Bettinger 1980, Mithen 1990) and the need for dietary

variation (Keene 1981). Yet, it is important to note that these criticisms are found in all

varieties of model. However, because a model cannot be based on direct observations of

the precise variables of prey and hunter, the very reliance of all models on surrogate data

suggests that the pursuit of quantitative precision is not necessarily desirable.

Although Jochim (1976) commented that the patterns of substance are adapted for

Germany and the Mesolithic and should not be generalised, the European nature of the

ecological data used in his model does allow for some adaptation. Price (1978, 1980), for

example, applied a variation of the model to the Mesolithic of the Netherlands. Jochim's

(1976) resource schedule has also proven useful in areas where the resource data is

restricted to larger game animals, for example, Zvelebil's (1981) study in Finland. Jochim's

model has, however, been criticised by Spikens (1999, 59) as not being objective, and

relying on individual opinions about which resources ought to be important, citing the

current lack of knowledge of the Mesolithic environment and resource. Spikens does,

however, acknowledge that the large game components of the model are reliable and

notes that the issue of defining resources is a complication that affects all such models.

Given that this thesis seeks to observe the relationships between landscape change and

population, the utilisation of a qualitative model seems appropriate. Indeed, given the

scarcity of data as outlined in Chapters 1 and 2, the utilisation of a quantitative model with

its reliance on large numbers of variables would be questionable. Conversely, the relatively

small range of values in a ranked relationship, as required by a qualitative model, is likely to be more robust in its assumptions. Any relationships observed, therefore, are likely to have a higher confidence level for archaeological application than that of a quantitative model. The use of a simpler model, derived from Jochim's 1976 model, also facilitates greater control over the assumptions made. Models, such as Jochim's, cannot, by their very nature, represent the whole of reality. However, the fact that this thesis seeks to observe and assess the impacts and effects of landscape change upon the human population means that it does not need to assess absolute values. The relative rankings produced by Jochim's model are adequate to facilitate a greater understanding.

Whilst many of the models which will be discussed seek to locate archaeological sites, the definition of an archaeological site is problematic (Dunnell *et al.* 1983). In Mesolithic studies this is often defined by any human activity, even a small flint scatter. In landscape archaeology the concept of seeing human activity in its environment adds further complications (Dunnell *et al.* 1983, Gaffney and Tingle 1984). An archaeological site is, in reality, a place where evidence of the past is preserved, and can vary in both definition and spatial extents dependant upon the period of investigation. Frequently, however, it is taken as an area of human activity, if this is considered palaeoenvironmentally, this definition could be taken to extend to entire landscapes! Even Mesolithic modifications of the landscape through burning (Dark 1998) could be seen in this light to represent some form of site. It is not the purpose of this thesis to discuss this in depth; If further detail is required the reader is pointed towards Foley's (1981) useful investigation of these issues. In this thesis, a larger definition will be taken to reflect its landscape goals. As such any

future use of the term "site" will reflect an area of archaeological activity within the landscape.

4.1.2 Introduction to predictive modelling

When the subsistence base of the population has been determined, the location of a population subsisting on those resources will need to be calculated. This is important when determining the impact of change on population locations. To achieve this, the thesis will utilise predictive modelling. Some of the earliest work in this field was performed by Wiley (1953) in respect to prehistoric settlement within Peru. Wiley successfully developed settlement archaeology, and his work provided the stimulus for other settlement studies to be conducted. Such techniques were improved by Flannery (1968) to allow a consideration of the landscape and environmental variables which could contribute to such prediction. Binford (1980) added to predictive modelling by producing a model that included sedentary behaviour, as well as a consideration of storage practices for boreal regions. Such work has led to applications that specifically focus on the Mesolithic and the issues of sedentism and complex patterns of behaviour (e.g. Rowley-Conwy, 1983, Price, 1985).

In archaeology, a predictive model is generated with the goal of predicting the likelihood of the presence of archaeology within an area. Predictive modelling attempts to achieve this through the identification of relationships to environmental variables (e.g. slope, aspect, location of water; Green 1973:287, Parker 1985, Kvamme 1985). However, this does not necessarily exclude the use of social variables and the input of existing archaeological information (Reynolds 1976). The application of GIS to predictive modelling has had a

profound effect, facilitating a uniform analysis of large areas up to and including at a

landscape scale (Sebastian and Judge 1988). Indeed, the rapid progress of computer

technology has allowed for much improved automation and resolution of predictive models

from the 1980's onwards (e.g. Kvamme 1986, 1990), and the very nature of a GIS database

facilitates rapid model updates and revisions. These developments have been utilised

within the two distinct types of prediction; that of inductive and deductive models (Kohler

1988:37, Wheatley and Gilling 2002).

4.1.3 Deductive modelling

Deductive modelling requires a prior knowledge of the anthropological or archaeological

knowledge of the targeted human behaviour within the area, and produces mechanisms

within the model that determine site location through a general theory of behaviour. As

Sebastian and Judge (1988 7, 8) observe, these models are more general and powerful than

inductive models, but within archaeology, are extremely difficult to create and validate and

so are less common (i.e. Kamermans, 2000). Kohler and Parker (1986, 432) observe that

deductive models must have three specific criteria. These include how humans make

choices, the goals behind those choices and variables affecting the location of sites, which

can be directly compared to archaeological data. The assumptions upon which these

models are based, in particular defining the mode of human behaviour, has led to criticism.

This focuses around the method of deduction of cultural relationships, which are often

subjective issues, especially for the prehistoric period (Kohler 1988:37).

4.1.4 Inductive modelling

These difficulties led to a more frequent use of inductive modelling within archaeology; Warren (1990, 91) defines inductive modelling as using existing knowledge to predict trends, and such models largely use physical variables. The most commonly used variables are aspect, slope, soil type etc., the use of which can be exemplified by Kvamme (1992), Brandt *et al.* (1992) and Kvamme and Jochim (1989). The models pursue correlations between known site locations and features of past environments. The use of environmental variables can be employed on a large scale; this is exemplified by Stancic's (2001) model of the Pomurje landscape in Slovenia.

Inductive modelling can, however, be subject to criticism; Dix *et al.* (2004) states that inductive models rarely take into account post-depositional transformations of the landscape, and that they rarely explain the correlations between sites and environments. Gaffney and van Leusen (1995) note that the strong emphasis on environmental data over that of cultural behaviour can lead to "environmental determinism". They also note that, in reality, social factors may well have played as great a role as environmental ones in determining site locations. Dix *et al.* (2004), however, observe that efforts are being made to redress this balance (e.g. Gaffney and van Leusen (1995) and Stancic and Kvamme (1999)), but that this is still a highly subjective task. Despite this, these models remain commonly used within archaeology (Church *et al.* 2000).

Both of the methods have been critiqued, and their effectiveness questioned (Kohler and Parker 1986:398). There are concerns with predictive modelling that need to be addressed.

The most fundamental relates to the archaeological record and its incomplete nature.

Much of the archaeological record is derived from sites which are easily accessible. Sites

which are deeply buried, or are less inaccessible, tend not to be included or considered.

Thus, when considering the archaeological record within a predictive model, the validity of

the record must be considered. In addition, it is important to be aware that the model may

result in a self fulfilling prophecy, predicting "known" site types and distributions. Whilst

this may not appear an issue, there remains an unknown element of the settlement pattern

which is not considered and which may impact upon the results. In this scenario it becomes

possible that a model will miss important archaeological areas, because they differ from

those expected by the model. Indeed, this is an aspect which is worthy of consideration,

especially when applying the results from one region to another. In addition to

archaeological data, other data inputs have potential error, either due to scale or method

of recording, and these may be perpetuated in the predictive model. As an example,

Kvamme (1990:114), whilst working on a regional model, observed flaws in the resolution

and quality of digital terrain data that could have caused a major impact upon the

predictive model. Fitch *et al.* (2005) observes similar phenomena in relation to bathymetric

data within the marine sphere. Ultimately, therefore, the predictive model can only reliably

operate at the scale of the lowest resolution data utilised within the model.

It must also be noted that temporality of most predictive models is, at best, general

(however, see Lewis and Murphy (1981) for a notable exception). This, in part, is due to

resolution aliasing inherent within the archaeological record. It is also true that changes

within the physical environment also occur during these periods of time in north western

Europe. For example, within the Mesolithic period, not only does the climate and vegetation change markedly, but the nature of the physical landscape available to the Mesolithic population radically alters due to marine inundation. The static nature of most models therefore limits their applicability. A predictive model can, therefore, be seen to be constrained by its temporal resolution. This in turn is limited by the temporal coverage of the input data. The level of temporality within the predictive model must, therefore, represent some meaningful level of resolution. As this thesis is examining the Mesolithic period, which is best determined at the environmental time scale, a "time slicing" of approximately 500 years will be utilised. This was determined to be a suitable time interval at which the temporal resolution of the available environmental data fitted. Further, an interval below 500 years would be unsuitable for the available sea level data (Shennan 2000). The 500 year interval also represents a level of resolution at which responses to physical and climatic change can be reasonably observed. If this was investigated at 1000 year steps, the investigation interval (10,000BP to 7,500BP) would be divided into only 3.5 steps.

4.1.5 Predictive modelling In submerged prehistoric landscapes

The principle benefit of predictive modelling to assist the research of submerged landscapes is noted by Flemming (1983) as its ability to dramatically reduce search areas. This observation has been infrequently pursued in submerged landscape research. However, there are published exceptions such as Dunbar's (1991) model of submerged palaeo-indian sites in Florida. However, these predictive models have met with mixed results, largely due to the obscuring effects of more recent sedimentation. Yet, utilisation

of predictive modelling in the marine sphere, based on 3D seismic data, offers several advantages, especially when considered in relation to those models based on bathymetry or in comparison to terrestrial counterparts. The use of bathymetry (the current seabed) as the basis for most kinds of predictive model, is of positive benefit in the marine sphere, as it is usually the main or only data type available for predicting submerged prehistoric sites. However, the lack of available archaeological information, the difficulty in accessing other datasets (Bunch *et al.* 2007) and the problems of recent sedimentation (Fitch *et al.* 2005) exacerbates the issues associated with this situation. The availability of three dimensional geophysical datasets offers a solution to these issues. 3D data allows for the quantification and identification of a landscape and its changes (Gaffney *et al.* 2007) in a manner which is rarely available for the terrestrial environment (Church *et al.* 2000). The use of 3D data, therefore, provides the solution to many of the significant issues which have been observed to hinder the generation of a reliable marine predictive model (Spikens and Engen 2007:28).

Additionally, the datasets utilised may be of varying resolutions and qualities. Thus the predictive model can only be expressed in terms of the coarsest resolution used. This is significant, since the resulting cell size may be so large as to limit the archaeological usefulness of the resulting model. As observed previously in this thesis, many of the earlier bathymetry models have been expressed in cell sizes of 1km (e.g. Lambeck 1995) and are clearly unsuitable for meaningful archaeological use. Whilst 3D seismic data used by this thesis uses a cell size of 12.5m, it is clearly larger than most Mesolithic sites. This means that the value of the 3D seismic derived model here is limited to application at a landscape

archaeological scale. However, it is important to note that petroleum industry 3D seismic data can be expressed at higher resolutions, new developments such as HD3D seismic survey offer to considerably increase this resolution (Fitch *et al.* 2009; Cuttler *et al.* 2010).

Whilst the Danish record offers some ideas about what to expect in the southern North Sea, its position prevents its use as a reliable proxy for this area. Perhaps more significantly, the British terrestrial record is largely based upon areas that would have been distant from the coast during that time. It is difficult to see how this information could be usefully utilised within a model of coastal regions. Significantly, the recent discoveries at Howick (Waddington 2007) and Goldcliff (Bell 2007) balance and challenge many of our previous archaeological assumptions. Given the proximity of these regions to their contemporary coastlines, it suggests that a markedly different pattern of sites should be expected in the southern North Sea. The limitations, both practical and financial, imposed by the deeper marine environment upon diver survey, determine the need for targeted survey to a much greater degree than that of the terrestrial realm. Unfocused surveys for archaeological sites without a predictive model in the marine zone is risky, and at worst, an exercise in futility. Thus, there is a real need for focused archaeological survey. Finds and negative results can be utilised to improve a predictive model in this area. As the model produces testable hypotheses, a positive feedback loop of understanding can be used to improve archaeological knowledge and further refine the model.

When these issues are considered, there is a clear need for a predictive model for this area of study. Yet, to date, the only model for Mesolithic northern Europe is the Danish fishing

model. This model, proposed by Fischer (1988, 1995), is based on bathymetric data, and derived from the ethnographic and archaeological record of Denmark. Fischer observed that discussions with fishermen who practiced traditional practices yielded valuable insights into the topographic influences upon site location which greatly aided the generation of the model. These interviews showed that a well defined set of characteristics existed for this type of fishing, and that it might extend back to the Mesolithic (Fischer 1995, 374). These characteristics led to a set of model rules (Figure 4.1, Fischer 1995, 374). Testing of this model has occurred over a long period of time (Fischer 1988, 1995, Fischer and Pedersen 1997 and Fischer 2004). Fischer reports a success rate at above 80%, with the caveat that success rate falls with increasing water depth. This, Fischer suggests, is due to increased sedimentation in those regions. Recent developments using the model in conjunction with maps made from 2D seismic surveys have performed well in these areas (Fischer 2004).

However, Dix *et al.* (2004) observes that this approach has not been tested in a variety of submerged environments, and may be limited in usefulness to Denmark. Dix *et al.* (2004) also state that all the material recovered using this model post dates the early Holocene, and may not be appropriate for the earlier archaeological periods. In addition, this thesis will suggest that the model's definition and mode of application has yet to be published to an adequate level to facilitate its utilisation within a computerised predictive model. The published method (Fischer 1988) leaves open the possibility that the model's success may be based upon the unquantifiable element of user experience, and it may not be possible to produce repeatable and reliable results. Further to this, Dix *et al.* (2004) also observe that a model which could be applied on the British Continental Shelf should contain a combination

129

of inductive modelling (i.e. Fischer 1995), as well as incorporating archaeological variables from British terrestrial sphere. Dix *et al.* (2004) highlights several pitfalls, identifying landscape geomorphology, the landscape scale and choice of suitable temporal periods as areas of difficulty. Spikens and Engen (2007:27), for example, observe that for the North Sea, "predictive models are inapplicable until the prehistoric land surface is reconstructed". These issues have been emphasised in previous sections of this thesis to be resolved by the use of 3D seismic data. It is therefore apparent that a predictive model utilising 3D seismic data is an achievable prospect.
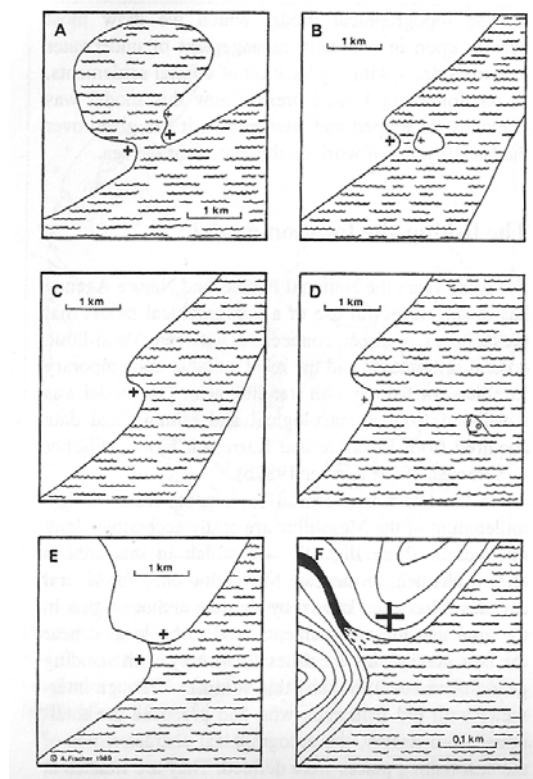
Figure 4.1 General topographic rules for Mesolithic coastal site location (after Fischer 1995)

Key for Figure 4.1 (as taken from Fisher 1995)

A = along a narrow inlet connecting large water surfaces, and with considerable hinterland

on both sides. Here the most potential site locations are immediately beside the

narrowest spot.

B= along a narrow inlet between a small island and a mainland. Here the most potential site

location would be on the mainland side.

C and D = at the tip of a headland. The probability of finding settlement remains is greatest

if the headland juts into sheltered water without strong waves.

E and F = at the mouth of a larger stream or river. Here the most potential site location is on

relatively flat land.

131

4.1.6 Introduction: Discussion

Providing both a qualitative and a predictive model for any area is a complex and difficult task. There are many unknowns which have to be determined and assumptions which have to be made. For both, these assumptions create a challenge similar in nature to that of generating a model in a terrestrial environment. However, the nature of the marine environment adds other complications, including burial and erosion, which make such a model a difficult proposition. To achieve the goals set out in Chapter 2, it will be necessary to divide the model into two main phases. Each phase, once implemented, will seek to address the objectives stated at the introduction of this chapter.

The phases will be comprised of a qualitative model and a location model. The qualitative model will seek to assess the food resources available to a population (**Objective 2.1**). Once these have been determined, the data will be applied to the mapped landscape. This will output a methodology which will assess the total resources available to support human occupation (**Objectives 2.2 and 2.3**). The location model will utilise a simple layered approach to predictive modelling, with significant factors derived from the earlier phases being 'weighted' according to their suggested impact on the settlement pattern (**Objective 2.3, 2.4**). Each phase will have a specific purpose, and each model will build consecutively upon the outputs of the previous phases. Both models will be divided into a series of distinct temporal phases, for which the assumptions and variables can be more clearly understood and constrained. This will be undertaken to assist in achieving **Aim 2** (create models of human resource use and population) and enabling **Aim 3** by allowing an assessment of the effects of sea level change on human subsistence within the study area.

4.2   Methodology: Qualitative model

4.2.1 Food resources

Food is a basic requirement for any human society. The floral element of this model is

difficult to calculate for the study area, given the scarcity of direct palaeoenvironmental

evidence for the area. However, Zvelebili (1994) demonstrates this could be estimated for

Mesolithic environments from modern analogues. Future improvements to the model

could include such information. However, the environmental model does make some

predictions for trees, including hazel, which could have provided food resources. It was

decided that whilst the floral resources were likely to have impacts upon hunter gather

societies within the region, the use of the larger fauna would be utilised for the model.

These large fauna have data that is more readily available from modern populations to

support a model (e.g. Smith 1992). Additionally, this evidence, with restrictions and

limitations, is likely to provide a more reliable indicator of possible places of hunter gather

concentration. Indeed, we have direct evidence for the presence of large fauna from

trawling within the North Sea. This record details the presence of the boar, red and roe

deer as well as auroch and elk (Kolfschoten and Essen 2004, 78). Auroch and elk, due to

their low numbers, are only likely to be very minor inputs into the diet (Jochim 1976).

However, it is apparent, from the base environmental model, that the marine environment

is important, and data from nearby Mesolithic coastal sites show the exploitation of the

marine sphere in the form of fish, seals and even whales (Waddington 2007, Clark 1980,

Coles 1971).

4.2.2 Generation of qualitative model: Terrestrial food resources

Values for terrestrial species were based upon known European populations who live in environments that are broadly similar to those in the environmental model. For example, figures for red deer densities were applied from an average of observed values from European sources as provided by Jochim (1976) and Smith (1992). The change from Boreal climate to an Atlantic one would have caused changes in the forest cover of the area. This would have increased the cover, which would be less favourable to these species. These impacts are factored into the equations by using values from modern areas with similar conditions, and applying them at the appropriate time period.

A similar rationale was applied to all the main faunal species, taking account of the impact of the environment upon the group sizes, and their location preferences upon population density. This data was acquired from suitable analogues as provided by Jochim (1976), Smith (1992), Clutton-Brock and Albon (1989) and Mattioli and Pedone(1995). This data was then tabulated, and is presented in Table 4.1. However, it must be noted that, whilst these values provide reasonable input, there is an unquantified, anthropogenic variable affecting most of the faunal populations in Europe. Many of these species have experienced hunting, loss of habitat as well as disruption of natural food chains. A classic example is the effect of the lack of natural predators (bear, wolf) on red deer from the Isle of Rum and subsequent human management (Nussey *et al.* 2006; Coulson *et al.* 2004).

Resource	Av. Weight (Kg)	Group Size	Mobility	D. per Km(sq) (Land)
Beaver	20	5	1	1.3
Boar	135	13.5	1.4	12
Fish FluvioLacustrine	1.2	3	0.05	98
Red Deer	217	13	1.5	4
Roe Deer	34	2.5	1.2	12
Small Game	3.6	2	0.2	103

Table 4.1 Population aggregation sizes and individual weights used in the terrestrial section of the model (data derived from Jochim (1976), Smith (1992), Clutton-Brock and Albon (1989) and Mattioli and Pedone(1995)).

4.2.3 Alterations to Jochim's (1976) qualitative model: Addition of marine fauna

The model data was expanded to allow it to accept values for marine species. To present available marine resources within the landscape, the values for marine faunal populations were applied in a buffer some 500 metres wide from the coastline. It would be highly difficult to model any resource procurement at sea, but many ethnographic examples (e.g. Hudson 1981) suggest that hunting marine mammals occurs close to shore. Spikens and Engen (2007:31) believe the availability of this resource to have imparted a significant "pull" to prehistoric peoples. Indeed, in the case of seals, their seasonal habit of pupping, moulting and hauling up onto the land would have been highly attractive, as they occur in distinctive and identifiable zones which could be accessed from the shore. Even marine fishing in the Mesolithic is most likely to have been shore based. Pickard and Bonsall (2004)

observe that there is little or no evidence to support any assertion that offshore or open sea fishing occurred in the Mesolithic. Indeed, they note that all the observed fishing activities identified could easily be conducted in inshore waters with or without boats. It is, therefore, reasonable to assume that the use of coastal buffers in this research to simulate Mesolithic marine resource procurement is acceptable.

4.2.4 Generation of qualitative model: Marine food resources (Cetacean)

The record for marine species provides a distinct and unique problem. However, the UK is fortunate in that it possesses a usable record of its marine fauna. For example, the UK record for whale stranding. This data was obtained from the Natural History Museum's Whale Strand Record, which has run since 1913, when an agreement with the then Board of Trade, charged the Natural History Museum in London to monitor cetacean strandings. Since then, there has been a continuous record. However, it must be noted that changes in recording methods suggest that only the most recent information can be regarded as truly representative. Additionally, as anthropogenic stranding factors are likely to be present in the entire record, there remains an uncertainty about natural stranding numbers within the record. Whilst this is unfortunate and may spatially limit the value of some of the data, values from the record such as stranded whale size and pod size still remain valid.

Using the data provided by the Natural History Museum, figures were calculated for large (1266.67kg) average strand weight over the decade 1980 -1990 and small (173.2 kg) average weight for the decade 1980–1990. Account was taken of small cetacean aggregation. Once the whale value had be calculated, it was observed that, on average for

a 1km stretch coastline, a whale was likely to be naturally stranded every two years.

However, in areas of favourable bathymetry this is likely to be significantly higher (Natural

History Museum [NHM] 2005). Further to this, it is likely that the numbers of whales

calculated (and hence possibly the number of standings) are low as a consequence of the

effects of modern commercial whaling, pollution and other anthropogenic factors (NHM

2005). Further, small whale species are likely to be stranded in family groups, with figures

of over 50 individuals being recorded [NHM 2005]. Such a stranding event would have had

a significant input into a hunter gatherer community.

Due to the low recurrence interval of stranding and the potential unreliability of the

modern data, whale stranding was, therefore, excluded as a regular food source in this

model. The cultural significance of a stranding event should not be discounted (see Clark

1952, 1947). Further, prehistoric whale hunting is possible through the utilisation of very

simple methods. Methods include "stoning" (similar to the ethnographically recorded

practices of Orkney Islanders [Fenton 1978]) to induce stranding. Indeed, Clark (1947),

through observation of antler picks in association with whale skeletons in the Firth of Forth,

notes that prehistoric man was very much aware of whales as an economic resource. If

whale hunting could be confirmed as being practised, then the calculated food values for a

stranded whale suggest even a relatively small catch would have a significant effect upon

the resource schedule for the region. These increased resources and the obvious dangers

of hunting whales, would have resulted in prestige for the groups performing this activity

(Clark 1947). Similar such impacts of whale hunting are ethnographically recorded for the

Makah tribe of Washington State in the U.S (Pascua 1991) and archaeologically for the

Jomon of Japan (Hiraguchi, T. 1993).

4.2.5 Qualitative model: Marine food resources (Seal)

The likely minimum Mesolithic seal populations can be calculated from data on present

populations of both Grey and Common Seals. Both species are present within the

archaeological record. Data for the present populations of common seal and grey seal

populations is readily available due to species protection legislation. Average values were

used in the model for population aggregation sizes and individual weights (see Table 4.2). It

must be noted that the population size, as with so many marine species, has greatly

suffered from anthropogenic factors including pollution, over fishing and fishery "catches"

of seals have greatly reduced numbers. The total impact of this is not fully understood

(Northridge 1988), but is thought to be significant (Julian 1994). Natural disease factors, in

part caused by anthropogenic activities, have also had a decimating effect. In 1988, Phocine

distemper virus (PDV) is recorded as having killed up to 18,000 common seals and 400 grey

seals from the area of the North Sea (Dietz R. *et al.* 1989, Heide-Jorgensen M.P. *et al.* 1992,

Jensen T. *et al.* 2002). Geographic and environmental factors for seal population

aggregation are possible to calculate and could be factored within a model. However, the

introduction of this complex variable exceeded the time available to this thesis and thus a

simple dispersal across the shoreline was utilised. It can, therefore, be argued that the

figures used in this research are, if anything, likely to be underestimates of the population

present during the Mesolithic.

Resource	Av. Weight (Kg)	Group Size	Mobility	D. per Km Coastline
Comman Seal	93.75	3	1.7	5.17
Fish Marine	1.9	3	0.05	60
Grey Seal	185	4	1.6	16.7
Whale (Large-Stranded)	1266.67	3.5	0.02	0.000765
Whale (Small-Stranded)	173.2	10	0.02	0.013322

Table 4.2 Population aggregation sizes and individual weights used in the marine section of the model. Note that both the grey and common seal values are averages of the male and female weight - this is necessary due to diamorphic differences.

4.2.6 Generation of qualitative model: Marine food resources (Grey Seal)

The mode of life of the two main species also have a great effect on their availability to hunting, grey seals, for example, tend to haul out on sandy shoals, beaches and islands. For procurement from some of these areas, it is possible that a simple water craft may be required. In addition, grey seals are vulnerable during August to October when the pups are born on land and stay near the birthing area with their mother for 3 weeks (Westcott 1996). When they moult in the winter months, the young are also vulnerable (Westcott 1996). Whilst the mothers are fierce protectors of their young, a possible deterrent to hunting, it must be considered that this does represent a hunting opportunity to take a mature female animal weighing some 150kg in addition to the pup (13.5kg) (Westcott 1996). As an alternative scenario, the pups could be preferentially predated, with low risk of hunter injury, when the mother returns to the sea for food leaving the pups helpless. Future improvements to the model could include such considerations.

4.2.7 Generation of qualitative model: Marine food resources (Common Seal)

The other seal likely to have been present in the North Sea is the common seal. These are elusive and tend to only haul out for breeding and moulting. The species lives in small groups although, in estuaries, they can concentrate into groups of up to 1000 individuals. It is obvious that such congregations represent a significant hunting opportunity for a hunter gatherer community. Indeed, the species tendency to stay in same area year round puts them at risk of hunting. The pups of the common seal are less vulnerable than those of the grey, being able to swim at birth. They are nursed on land for 4 weeks during the period between June and mid July (Bonner and Thompson, 1990), and this period could represent a possible summer hunting opportunity. Another useful period for hunting is during the June to September moult (Bonner and Thompson, 1990). During this period common seals regularly haul out onto sandy beaches and banks, offering a period of resource availability and stability.

4.2.8 Generation of qualitative model: Marine food resources (Fish)

For the purposes of calculating the likely (or extent of) Mesolithic fishing practice within the marine area, it was considered that the assertion of Pickard and Bonsall (2004) of coastal fishing was correct. Thus all fishing was considered to have been performed at or near the shoreline. Pickard (2002) identified over 80 edible fish species that are present at Mesolithic sites. All of these species are present today, and thus suitable analogues can be found. An average marine fish weight was determined from modern data for these 80 types, and this weight was factored into the model (Table 4.2).

4.2.9 Generation of qualitative model: Marine food resource summary

All the above species were likely to have been important resources to the Mesolithic communities of the North Sea. However, it must be observed that most of our knowledge is limited to larger fauna, and therefore any model must be interpreted with this in mind. However, archaeological isotope analysis (d15N) of the Staythorpe femur (Schulting and Richards 2001) shows that human diets with very high animal protein intake occurred within the Mesolithic. This could be interpreted as a bias towards a "meat diet", which would provide useful insights into the resource base of human occupations. It is, therefore, possible to use this information and suggest that the model preferentially focus on these large species. However, the relative simplicity provided by a focus on larger fauna species does not preclude a consideration of plant species. This approach could be considered in future iterations of this model.

4.2.10 Methodology: Jochims (1976) Qualitative Model formulae: Thesis specific modifications

Alterations to Jochim's (1976) formulas were made to remove the subjective element of non-food resource score. This addresses some of the criticisms levelled at the model, but also removes an element of uncertainty from the model as these values cannot be reliably determined for the North Sea. Thus, the secure income of food was expressed as

wd/m

Where w = weight of individual, d = faunal population density and m = mobility of fauna

Whilst fauna population aggregation at minimum cost was calculated using the formula

wa/m

Where w = weight of individual, a = aggregation size of fauna and m = mobility of fauna

These formulae were then used as direct replacements for Jochim's expressions (wnd/m and wna/m).

Application of, these formulas requires a determination of population densities, individual group sizes and weights for all the fauna species represented in the model. This involved the calculation of figures for the marine species for inclusion in the model.

4.2.11 Qualitative model: Application of modified Jochim (1976) equations

Jochim's (1976) model of resource use determination seeks to solve two basic problems

(here termed "risks") facing a human hunter gather population, that of providing a secure

food income and the yield resulting from the hunting. It is recommended for additional

information on the model, Jochim's 1976 publication "Hunter-Gatherer Subsistence and

Settlement" be consulted in addition to this section.

The first goal of the model seeks secure food income by attempting to solve the risk

involved in hunting a particular prey species. The risk associated with hunting a prey

species can be reduced in a number of ways. The first is to hunt a less mobile species (m) as

the chances of encountering and capturing a prey item are therefore higher. The other

option is to hunt larger items (w), or those with high population densities (d), as this

increases the return of a successful hunt. These variables therefore can be combined to

produce a formula which expresses this.

wd/m

Where w = weight of individual, d = faunal population density and m = mobility of fauna

The second of these goals is aggregation yield at minimum cost. This seeks to express the

effects of prey species group sizes upon a successful hunt. A prey species with a large

group size is more likely to offer an opportunity for a successful kill, and therefore a lower

resource risk, than that of a single solitary animal. To achieve this, the aggregation (a) of a

prey species is calculated and implemented within the formula.

wa/m

Where w = weight of individual, a = aggregation size of fauna and m = mobility of fauna

As a hunter gather community seeks to solve these risks for any one prey species, a combination of the two must be calculated. As fauna are not hunted in isolation, hunter gather communities often seek diverse range of prey species, dependant on their availability (Hill *et al.* 1987). Thus, for each risk, the score of each risk must be calculated, before being divided by the sum of all of the resource scores to allow for a determination of the resource use by a human community. As there are two primary risks this value must be calculated for each, before the sum of the two resource uses are divided by two to provide the total resource use.

This can be expressed in following manner:

secure food income total resource use (or SF) (%) = [resource wd/m]/[resource sum wd/m] * 100

aggregation yield at minimum cost resource use (or AY) (%) = [resource wa/m]/[resource sum wa/m] * 100

therefore:

Total Resource Use = (SF+AY)/2

For the purposes of this project, the values for mobility, aggregation and weight are expressed as dynamic values that change monthly (see Table 4.3). For terrestrial species, these values are primarily based on the existing model values (Jochim 1976), with modifications to take into account northern European conditions, such as the timing of fish

runs. For marine species, weights and aggregation values are expressed using values from

modern British populations, from data provided by the Natural History Museum (pers.

comms.). However, the aggregation values for seal populations, and possibly the densities,

are, if anything, an underestimate. This is due to modern anthropogenic interference in

these populations. The resulting values are expressed as a graph (see Figure 4.2). These

calculations were then repeated utilising prey species density values that typified both

Boreal and Atlantic environmental conditions. This achieved a consideration of each prey

species environmental preferences and then allowed the selection of suitable analogues for

the model. The final output is grouped seasonally to reduce any monthly bias.

Predicted Proportional Resource Use to Contribution to Total Yearly Diet (Atlantic)

Figure 4.2 A Hypothetical resource use graph for the Atlantic environmental stage. Note
the significant spikes related to the exploitation of seal resources. If this demonstration
was indicative, then this would suggest a reliance on terrestrial resources during the winter.

Yearly Mobility

Species	J	F	M	A	M	J	J	A	S	O	N	D	T Value	Check	Actual	Correlation
Beaver	1	0.2	0.2	0.2	0.2	1	1.8	1.8	1.8	1.8	1.8	1	12	1	1	100
Boar	1.4	1	1	1	1.4	1.5	1.6	1.6	1.6	1.8	1.8	1.2	16.7	1.391667	1.4	99.40476
Comman Seal	1.7	2	2	2	2	1	0.7	2	2	2	2	2	20.7	1.725	1.7	101.4706
Fish FluvioLacustrine	0.05	0.08	0.07	0.06	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.07	0.58	0.048333	0.05	96.66667
Fish Marine	0.05	0.06	0.06	0.05	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.06	0.59	0.049167	0.05	98.33333
Grey Seal	1.6	1	2	1	2	2	2	1.5	1	0.5	1	1.5	19	1.583333	1.6	98.95833
Red Deer	1.5	1	1	1	1.7	1.7	2	2	1.3	1.3	1.7	1.5	18	1.5	1.5	100
Roe Deer	1.2	1	1	1	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.1	14.2	1.183333	1.2	98.61111
Small Game	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.4	0.2	0.2	100

Yearly Aggregation (Average by Year)

Species	J	F	M	A	M	J	J	A	S	O	N	D	T Value	Check	Actual	Correlation
Beaver	5	5	5	5	5	5	5	5	5	5	5	5	60	5	5	1
Boar	13.5	14.5	14.5	14.5	5.8	5.7	11.9	11.8	11.6	15.1	15.1	5	162.5	13.54167	13.5	1.003086
Comman Seal	20	2	2	2	2	50	50	75	30	20	2	21	239	19.91667	20	0.995833
Fish FluvioLacustrine	3	1	1	2	4	5	5	5	5	5	1	1	37	3.083333	3	1.027778
Fish Marine	3	3	3	3	3	3	3	3	3	3	3	3	36	3	3	1
Grey Seal	19	2	2	2	2	2	2	2	50	50	50	20	229	19.08333	19	1.004386
Red Deer	13	21.7	21.7	21.5	11.4	4.9	5.7	12.3	14.1	10	10	11.4	156.3	13.025	13	1.001923
Roe Deer	2.5	4	4	4	3	2	2	1.5	1.7	1.7	2	3	30.4	2.533333	2.5	1.013333
Small Game	2	2	2	2	2	2	2	2	2	2	2	2	24	2	2	1

Yearly Mass / Weight (Average by Year)

Species	J	F	M	A	M	J	J	A	S	O	N	D	T Value	Check	Actual	Correlation
Beaver	20	20	20	20	20	20	20	20	20	20	20	20	240	20	20	1
Boar	134	149	125	126	95	102	118	128	139	147	161	165	1615	134.5833	134	1.004353
Comman Seal	74	83.5	83.5	83.5	83.5	46.75	46.75	59	70	83.5	83.5	83.5	890.5	74.20833	74	1.002815
Fish FluvioLacustrine	1	0.7	1	1.2	1.4	1.4	1	0.8	1.3	1.3	0.9	0.8	12.8	1.066667	1	1.066667
Fish Marine	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	13.2	1.1	1.1	1
Grey Seal	173	190	190	190	190	190	190	190	131	135	190	190	2078	173.1667	173	1.000963
Red Deer	216	205	209	218	207	203	221	236	242	216	225	218	2597	216.4167	216	1.001929
Roe Deer	33	35	35	35	31	27	31	34	35	37	32	35	397	33.08333	33	1.002525
Small Game	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	43.2	3.6	3.6	1

Table 4.3 The Values for Dynamic Mobility, Weight (mass) and Aggregation used within this model. The full listing of all the tables utilised within this model is provided in Appendix 1.

4.2.12 Generation of qualitative model: Determination of resource yield

Once the figures for the maximum possible resource yield had been determined, and the availability of the resource for human use calculated, it was then possible to add Jochim's equation to the resource matrix. The resource matrix calculates the number of people that the resource could support per square kilometre. To this, a binary matrix is applied, that allows the calculation of the presence or absence of a resource species. Once factors, including hunting intensity, are applied, and the resource yield calculated, it is possible to calculate the maximum resource energy available for human usage. The energy requirements for a single person in a year are defined by Jochim (1976) as 730,000 Kcals per annum. It is therefore possible to calculate the number of people per square kilometre. This calculation is performed by adding the total resource values for the schedule over the year, less a hunting efficiency constant [Given by Jochim (1976) as 20%] and dividing by the total energy requirements of a single human individual.

For example, for the resource common seal for the winter season a calorific value of 1,294,264.78 Kcals per km^2 of coastline is calculated. Of these, only 258,852.95 Kcals are available at a 20% hunting strategy. Since one person requires 730,000 per year (Jochim 1976), to calculate the number of people this could support, we must divide the Kcal value (258,852.95) by the requirement value (730,000). This gives us a maxima value of 0.35 persons being supported by the potential resources available per km^2 of coastline.

4.3   Predictive modelling methodology: Generation of a location model

Any predictive model for site location of hunter gather communities in the North Sea region must take into consideration a variety of factors which have been observed earlier in this chapter. Firstly, the scarcity of archaeological information from the North Sea itself makes it difficult to generate a suitable strategy. Any first generation model must, therefore, take into consideration information from the surrounding terrestrial and marine spheres in which comparable societies lived. Fortunately, from the Mesolithic cultures surrounding the North Sea (see Chapter 2), it is clear that there are some comparable areas which can be drawn upon to provide information.

It is fortunate that most of the required information can be easily acquired by using the 3D seismic information (See Chapter 3). The datasets required by the model that can be generated are the location of fluvial features (and hence distance to water), the position of shorelines and landscape topography. This information can made readily available for the southern section of the study area, and, as such, it is this area that was chosen as a sub section for the development of the predictive model. As observed in the previous section, Fischer's (1988, 1995) Danish fishing model provides a predictive model for submerged sites that exist in the Danish sector of the North Sea. This model derives strength from being based upon observations that topography influences site location. Additionally, testing and improvement of this model has occurred over a long period of time (Fischer 1988, 1995, Fischer and Pedersen 1997 and Fischer 2004). However, it must be observed that no variables or formulas have ever been published for this model. This research will therefore be unique in generating a GIS model based upon the *"principles"* proposed by the Danish

fishing model. The model will utilise a simple inductive layer model approach with various important factors being 'weighted' according to their activeness to settlement.

Topographic data for this model derived from the utilisation of the pick of the land surface in the seismic data which had been converted to depth (see Chapter 3). The initial stage of the model requires the contouring of slopes at one degree intervals (see Figure 4.3) to allow the model to predict a preference of gentle slope (see Figure 4.1). Since the Danish fishing model suggests that sites of the lowest slope will be chosen by hunter gatherers, a classification of the slope model was used giving the heaviest weighting to slope values below 5 degrees. Kuiper and Wescott (1999) in their GIS predictive study of prehistoric sites used "slopes less than or equal to 5 percent", a figure similar to that classified by Waddington (1999) as "gentle".

The relative sea level heights throughout the study period were extracted from Shennan's 2002 sea level curve for this area. This information was directly applied to the DEM (Digitial Elevation Model) generated from the topographic data. Areas of topography on the DEM which fell below this contour were then deemed to be submerged, whilst those above were considered to be land. A height of 5 metres above sea level was ascribed as the minimum height at which a site would be located to avoid tidal conditions. As a further restriction, a distance model was applied whereby all sites over 0.5km from the sea were scored a low figure (1) to compensate for distance.
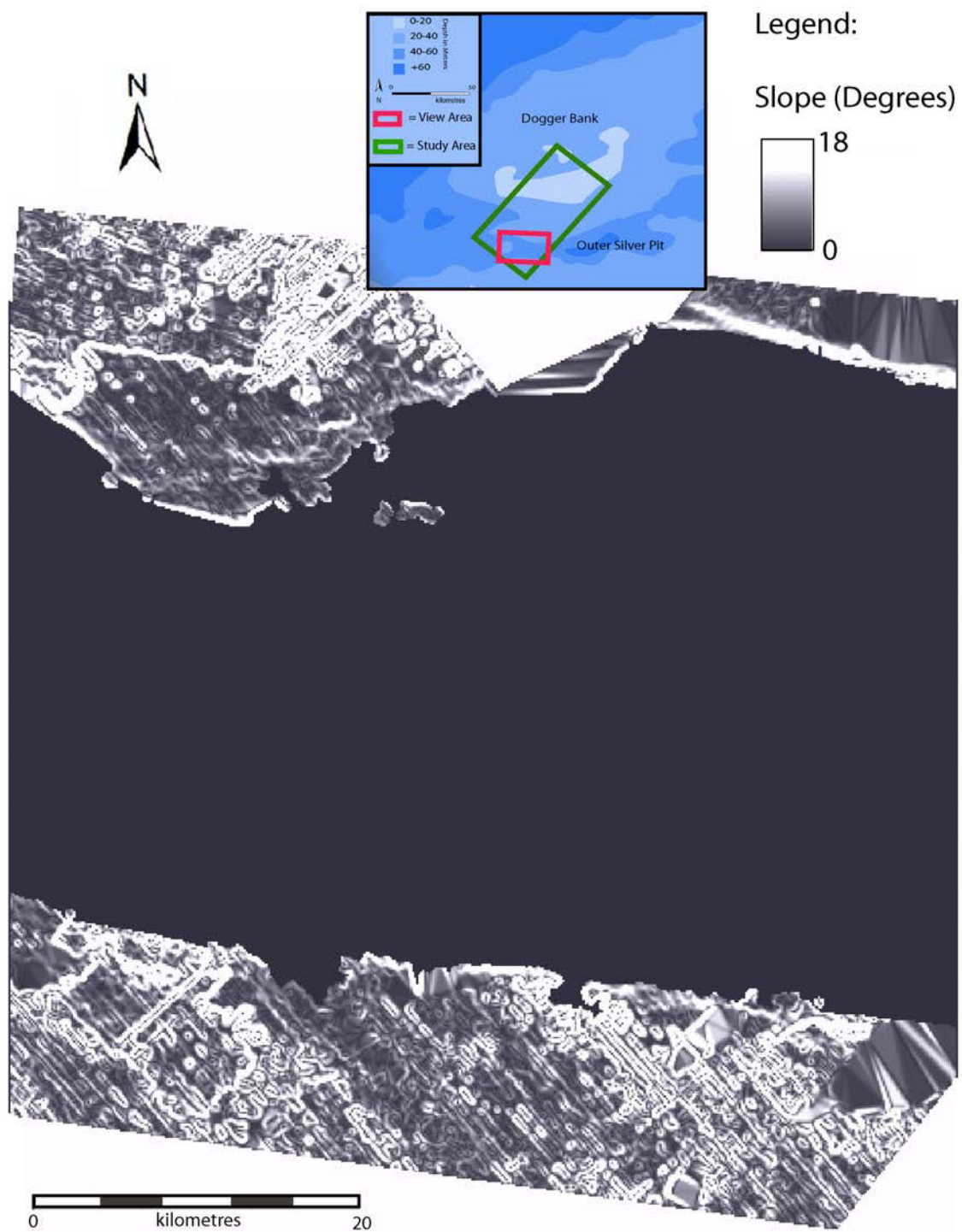
Figure 4.3 Slope model generated for use in the predictive model
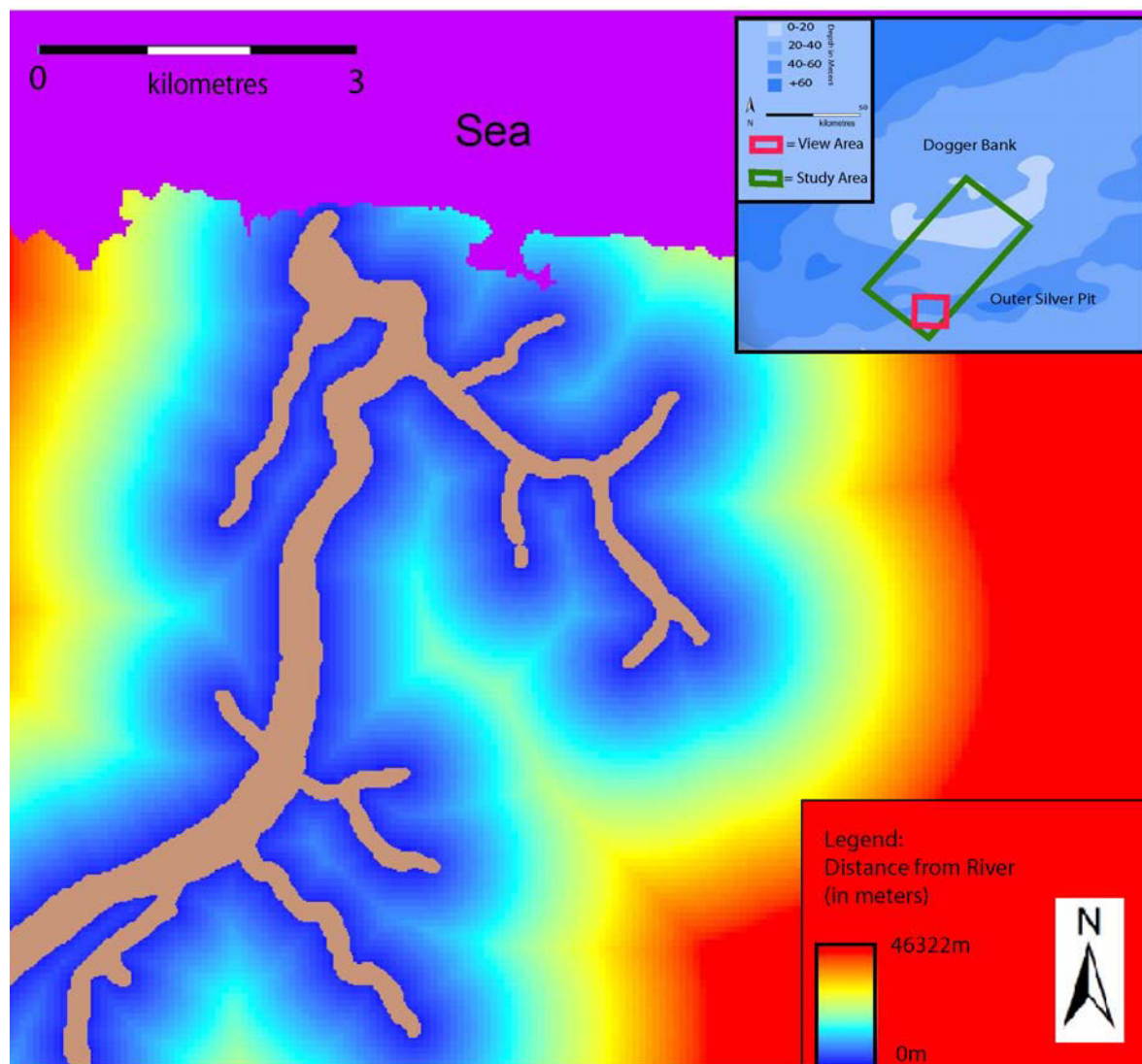
Figure 4.4 Distance model from a fluvial feature. From this the score is calculated, decreasing over a distance of 0.5km from the feature.
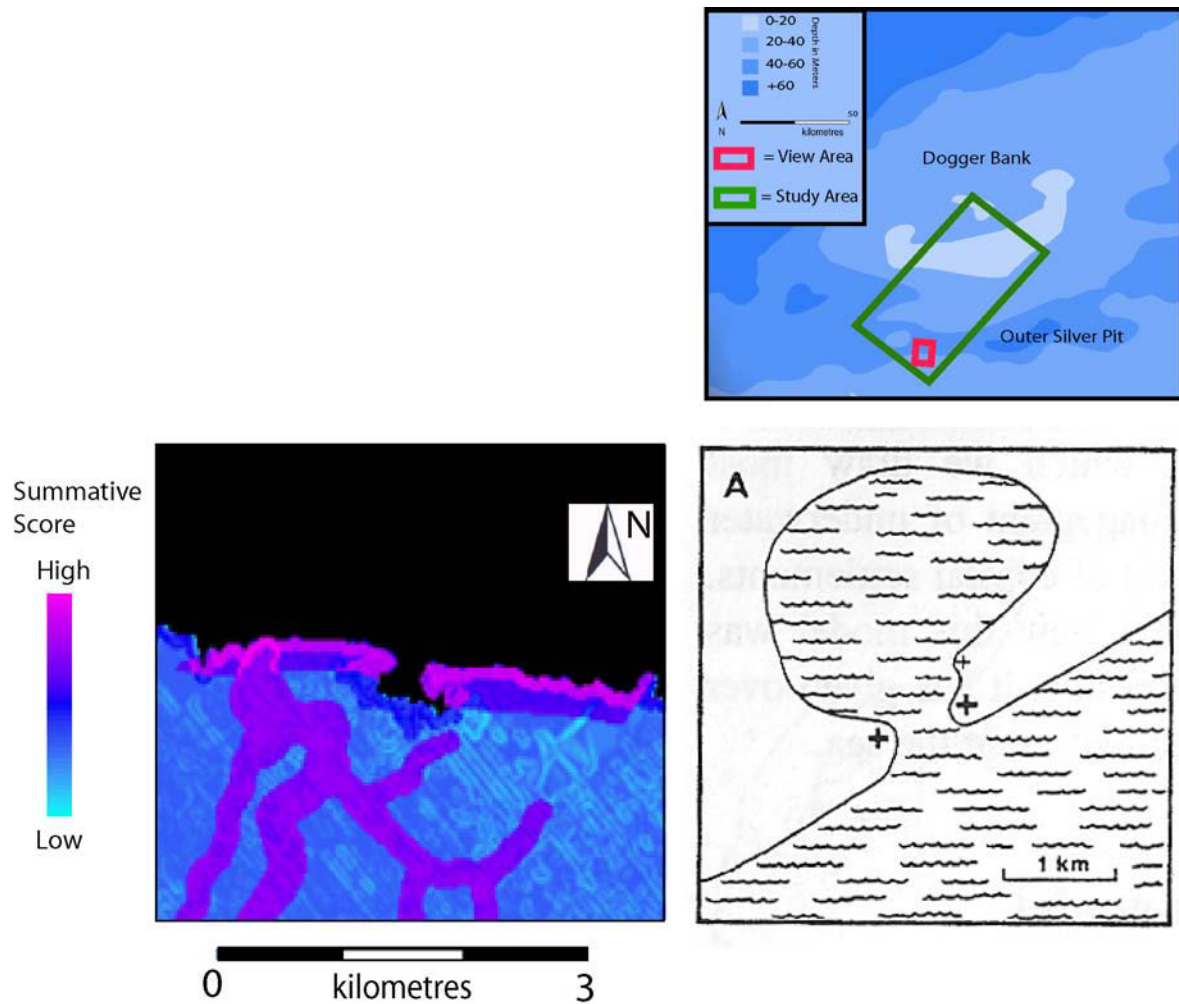
Figure 4.5 Summative distance mapping for coastline and fluvial features. It is apparent that the locations where the coastline is met by a river score highest (purple). A similar effect is seen in the embayment – this is comparable to the effect seen in the Danish fishing model (labelled 'A')
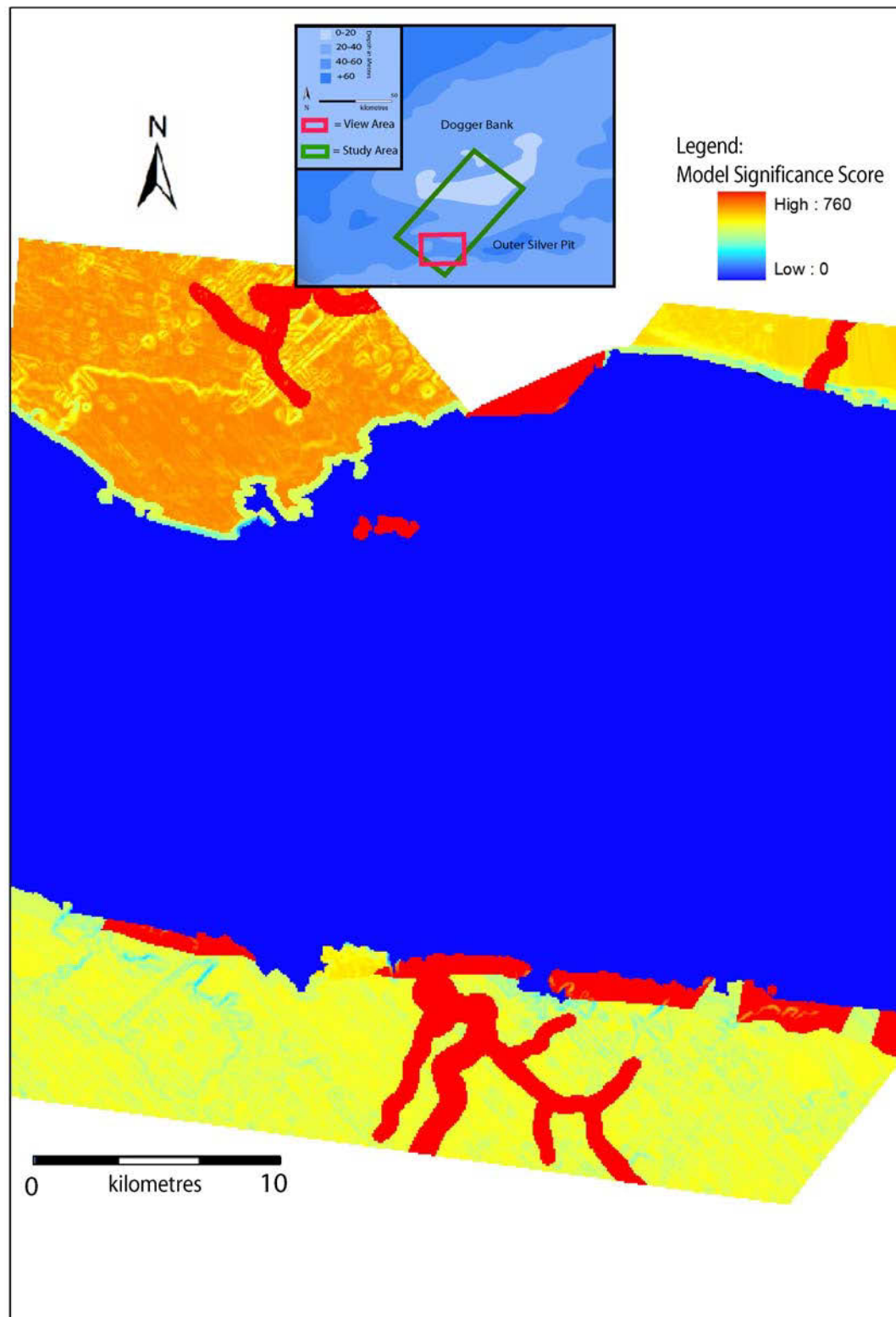
Figure 4.6 Resultant output from the layer combinations during the generation of the

location model.

The Danish fishing model asserts that the presence of fluvial features near the coastline

influences site location. Since the fluvial features located by the seismic data are likely to

represent the flood plain of a river, rather than the channel itself (in a similar manner to

that observed by Posamentier, 2000), it was considered that the distance from these

features would be sufficient to describe their effect on the model. Scores were therefore

ascribed, which placed the highest value in the floodplain itself, whilst the score decreased

over a distance of 0.5km from the feature (see Figure 4.4). Areas beyond 0.5km were

ascribed a low value (1).

To account for the effect of islands and safe harbours upon the Mesolithic population, as

suggested by Fischer, a further distance model was applied to take into consideration these

features. This calculates a score weighting for the islands, and is overlain in a summative

manner with the fluvial and coastal distance models. In such a way the presence of

estuaries are recorded. Additionally, the effect of the presence of an island upon the site

location is represented through a similar overlap in the distance scores. This, therefore,

replicates the effects for both type of feature as observed in the Danish fishing model (see

Figure 4.5).

From the data layers produced, an assessment was made of the layers deemed to be most

relevant to the production of this model, based on their attractiveness to hunter gatherer

societies. The most significant layers were determined to be the factor of slope, distance to

fresh water, type of Mesolithic vegetation, and proximity to the coastline. Other layers

which include the position of islands and inlets were also allowed for the incorporation of

harbours and sheltered waters. Once these layers had been compiled, they were

reclassified on a scale of 0 to 255, where 0 is least attractive to hunter gathers and 255

most attractive. The resulting outputs were added together to allow a quantification of

probable site location. The resultant output layer offers a modelled significance of the

importance placed on the coastal areas (see Figure 4.6). Catchment analysis was then

performed on the output as a final stage of the methodology.

4.4   Predictive modelling methodology: Catchment analysis of predicted archaeological areas

Catchment analysis has a significant history in archaeology (i.e. Flannery 1976, Higgs and

Vita-Finzi 1972) and is defined by Renfrew and Bahn (2000) as "a type of off-site analysis

which concentrates on the total area from which a site's contents have been derived".

Whilst this theory has often been applied to farming communities, Hodder and Orton

(1976) observe that this model can also be applied to hunter gather societies. Indeed, this

was undertaken by Clark in 1974 for Star Carr (Figure 4.7). Catchment analysis derives its

origin from "least cost" principle (Thunen, 1966), and works on the basic tenet that the

further from a starting point a resource is, the greater the cost in procurement of that

resource. Eventually, therefore, there is an economic boundary that is reached where the

costs of exploitation exceed that of the resource being procured (Findlow and Ericson

1980). This analysis generates a ring of land use that surrounds the point of investigation,

the area within which a population is likely to gather its resource, needs. The capability of

GIS to easily compute cost surfaces (weighted by distance, slope etc...) allows the

consideration of obstacles or routes of travel on this economic cost. Gaffney *et al.* (1995),

note that, whilst catchment analysis considers the environmental factors, it does not take into consideration variables that can be caused by culture and ritual. However, catchment analysis remains useful, and can be used in conjunction with predictive modelling to allow a more thorough analysis of the predictions.
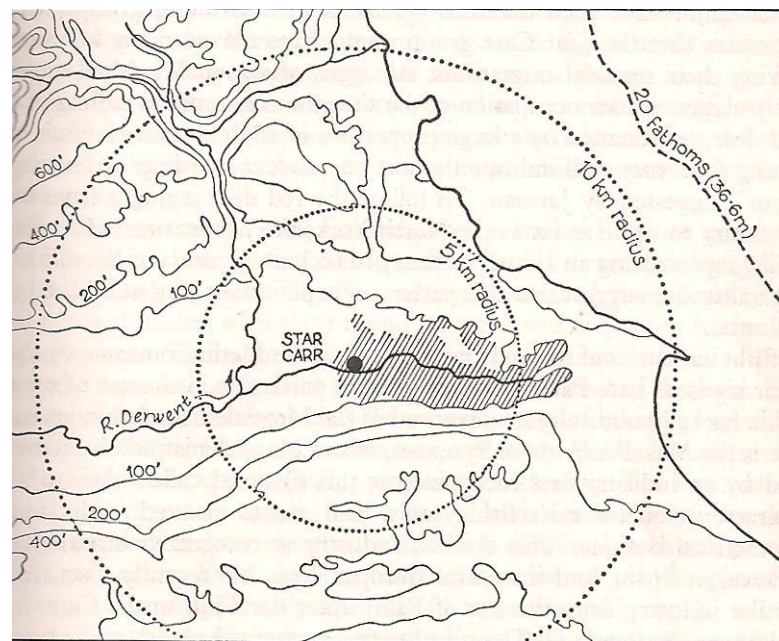
Figure 4.7 Catchment analysis of Star Carr, Yorkshire (after Clark, 1974, Fig 6)

This analysis is useful, since it allows for a consideration of elements not possible within the simpler predictive model. Factors such as seasonality, sedentism, site type and even migration associated with an area can be suggested through an analysis of the resulting output of data. Such information on the mode and style of occupation during the Mesolithic within the study area would obviously have great significance for the aims of this thesis. Therefore, in this study, the application of catchment analysis was performed to investigate the possibility that the range of resources allowed for sedentary behaviour

within the area. The application of site catchment analysis used within this project takes

advantage of "mapmatics" (the mathematical processing of raster images) ability within

ArcGIS's raster calculator. A cost surface was first determined utilising Pandolf's (1977)

equation (see below), which closely models human energy expenditure (Duggan and

Haisman 1992). This was subsequently applied to a slope model (Figure 4.3) generated

directly from the DEM (digital elevation model).

Pandolf's Equation

$M = 1.5W + 2.0(W+L)(L/W)^2 + n(W+L)(1.5V^2 + 0.35VG)$

Where M = Metabolic rate in watts

W = weight of unclothed person (KG)

L = Load of person (inc. clothing)

N= Terrain factor (dynamic)

V = walking speed (set to 3mph)

G = Grade (slope %)

To allow for a more realistic modelling of the terrain costs, a dynamic terrain coefficient

was used, which varied according to the vegetation and soil type in a fashion similar to that

prescribed by Givoni and Goldman (1971) and using values supplied by Marble (1996,5).

Marine areas were ascribed a co-efficient of 1.0 to allow a partial modelling of marine

transport (see Figure 4.8). Ideally, exact figures for the metabolic cost of moving a

Mesolithic vessel, such as a log boat, would be factored in the equations of movement over

water. This would allow for a much more accurate model of the costs of transport across water. Unfortunately, no data for this currently exists, and the information available is often unsuitable, as the vessel utilised are modern racing boats. From this information, a friction map was generated (Figure 4.9) to express the cost of travelling on this landscape.
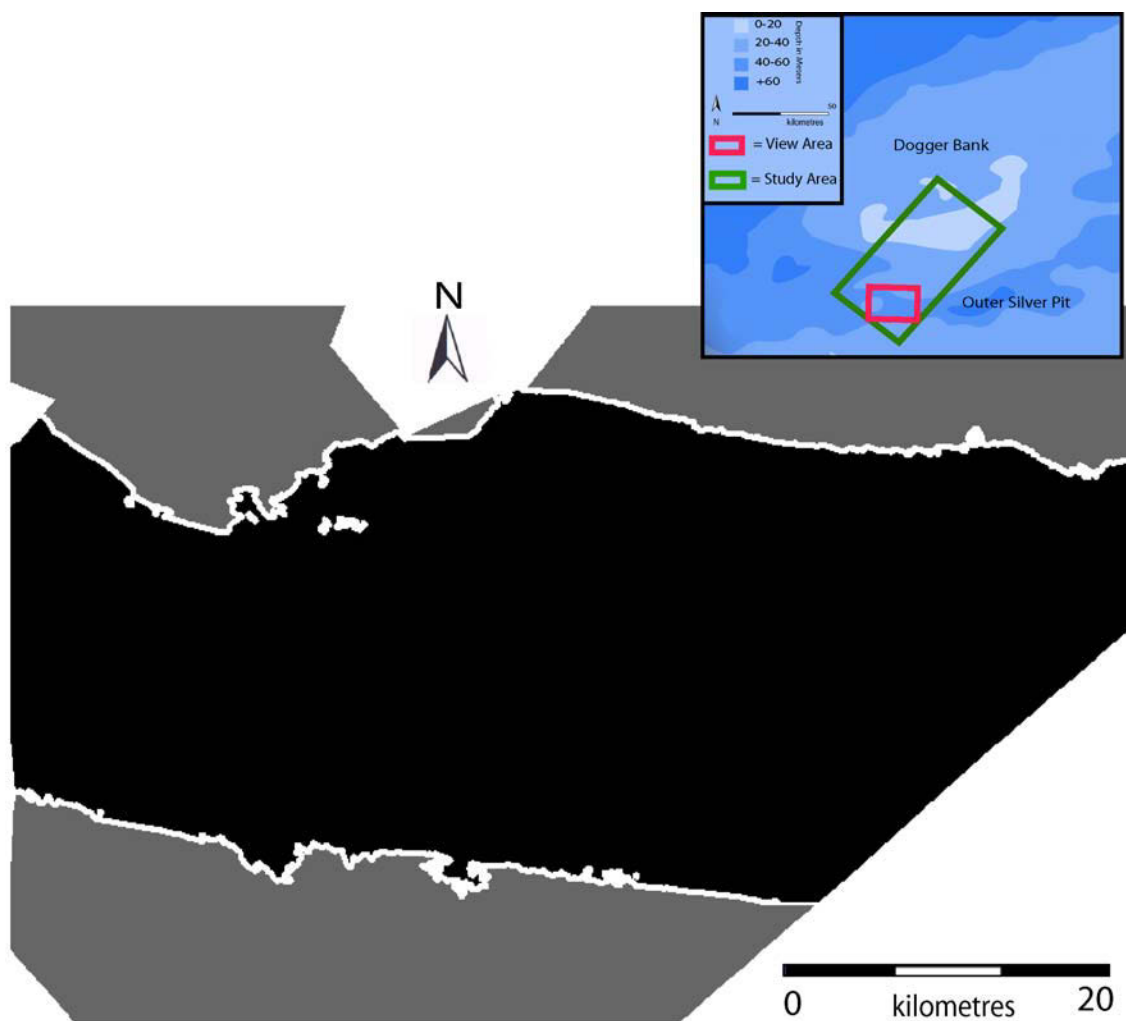
Figure 4.8 Map of terrain coefficient - Black = 1, White = 1.8, Grey = 1.2.
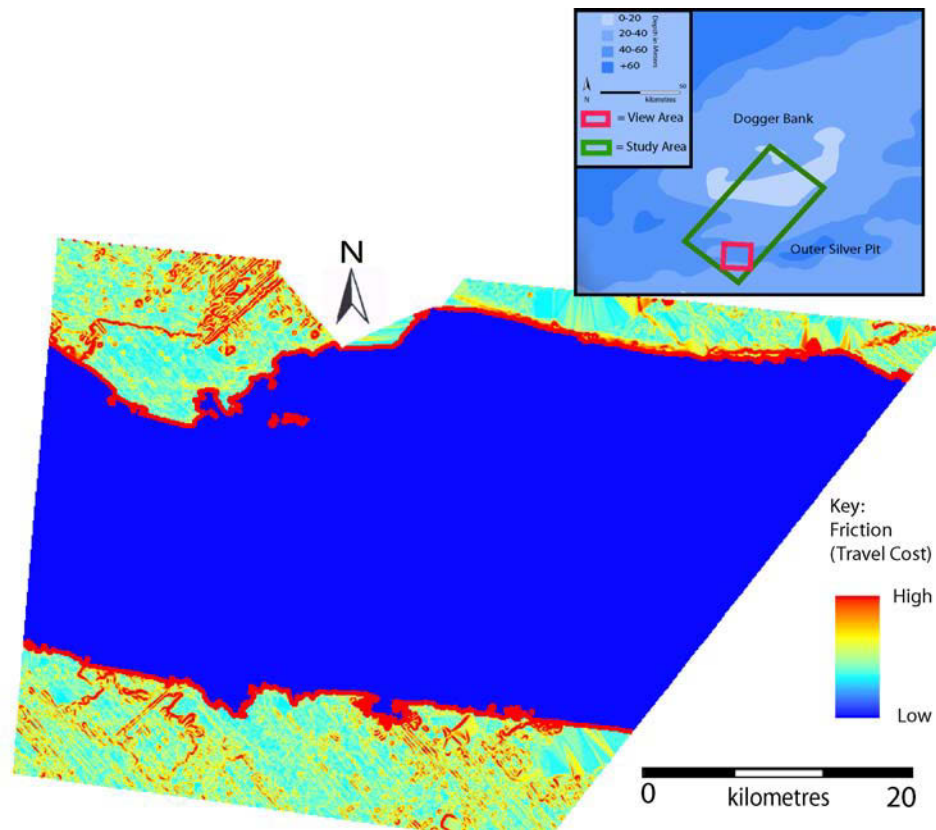
Figure 4.9 Friction map of the terrain (Red = High cost, Blue = Lower cost). The thin strip of

high friction along the coastal zone reflects the difficulty in travelling in this environment.
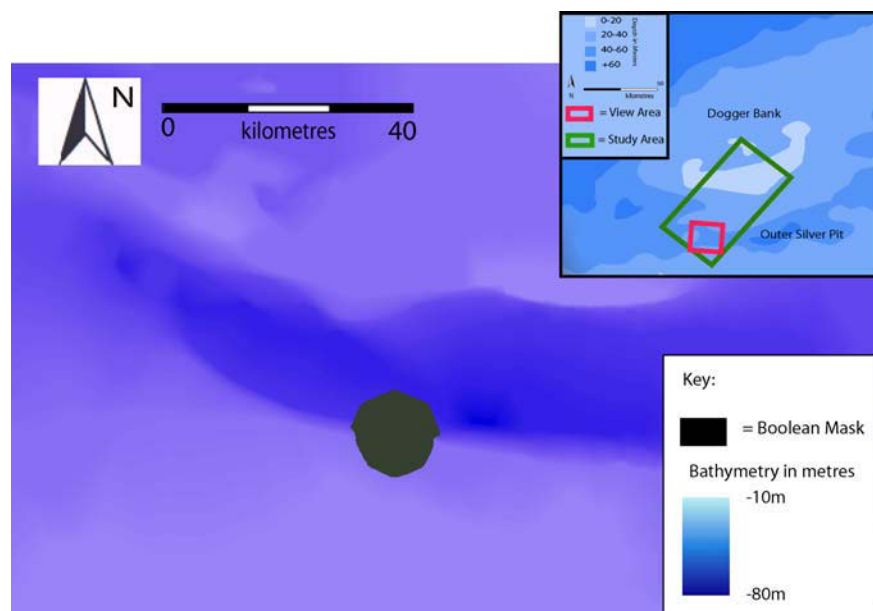
Figure 4.10 Boolean Mask for territory overlain upon a bathymetric image for the study

area

Once these had been produced, the cost of travelling from areas of archaeological activity generated by the predictive model was then calculated. This was achieved through the comparison of a model based upon the cost of travelling on a flat surface. This, therefore, determines the maximum energy expenditure value. This maxima value, once applied to the predicted site cost models, provides a determination of the size and shape of the catchments. Through the reclassification of the resultant catchment shapes into a Boolean mask by reclassifying the data into a simple binary presence (1)/absence (0) layer, it becomes possible to select the relevant data from the environmental model by multiplying the environmental layer with the Boolean mask (see Figure 4.10). This focused subset of the environmental data is effectively the resource available to occupants of a given area. As the subset contains the resource and subsistence data, a calculation using the values for human energy requirements allows for a calculation of the maxima population size within that area. Additionally, this result also allows for the relative comparison of productivity between predicted sites.

4.5 Modelling methodology: Synthesis

In order to achieve the aims and objectives outlined in Chapter 1 and 2 of this thesis, it was determined that both a subsistence and predictive model would be required. This chapter has outlined the methodology undertaken, and the scope of the two models that were be utilised. In doing so the chapter has achieved **Aim 2** of this thesis (to create models of human resource use and thus potential population) and its associated objectives.

Whilst the resource model will only produce qualitative results, it is apparent through the observations made at both the beginning of this chapter and that of Chapter 2, that the evidence base is unlikely to be able to support anything else. Given this situation, the provision of quantitative data for the study area would not be supportable. However, the fact that this thesis seeks to observe and assess the impacts and effects of landscape change upon the human population means that it does not need to assess absolute values. Thus **objectives 2.1** and **2.2** of this thesis are met by the production of a model of the food resources and the yield of those resources to a human population.

The predictive model methodology allows for a more focused examination of these results. Through the combination of predictive modelling with site catchment analysis, it will be possible to provide insight into the likely occupation patterns and subsistence strategy, thus the results will achieve **objectives 2.3** and **2.4**. This achievement will provide data that will resolve the research questions of this thesis. In the next chapter the results of the methodologies of both Chapter 3 and 4 will be provided and discussed.

CHAPTER 5

RESULTS

5.1   Introduction

This chapter presents the results of the methodologies outlined in Chapters 3 and 4 in order to allow a consideration of the objectives that are part of **aim's 1** and **2** (see chapter 1). As such, the results presented in this chapter will be presented in two sections. The first of these will be the presentation of the results of the primary dataset methodology (Chapter 3). The section will reveal the new information gleaned utilising the 3D seismic data. The provision of this information is vital, as it makes possible archaeological qualitative modelling within the thesis's study area.

The second section of this chapter presents the results of the qualitative and predictive models. Since the sequence of investigation is significant to the resolution of the aims of this thesis, the results of the qualitative model will be presented first. The qualitative model will demonstrate the relative changes in resource distribution, and ultimately population, both in spatial and temporal terms. The subsequent predictive modelling will allow for a consideration of the above data in terms of localised effects. It will allow consideration of objectives that are part of **aim 3** (see chapter 1). The utilisation of site catchment analysis in conjunction with this predictive modelling will assist in this understanding through changes in relative supportable population numbers at each predicted site through time.

This chapter therefore will provide the results which will satisfy **aims 1** and **2** of this thesis,

whilst the discussion and examination of the data from these two aims will address **aim 3**.

The assessment of the changes in population levels in relation to sea level change will be a

major contribution to **aim 3**. Indeed, the results of this chapter represent the first

application of a combination of qualitative and predictive models within the marine zone.

5.2   Primary dataset generation results: Introduction

The first stage in the methodology was the examination and interpretation of the 3D

seismic datasets, as the primary source of information for many of the data layers derived

for the thesis. Here, the interpretation of the seismic data will be presented and discussed.

Following from this, the results derived from the landscape layers within the GIS will be

presented. In the concluding section, the derived layers will be presented. Presentation of

the results of these datasets will then proceed to the next section, which will discuss the

results derived from the modelling.

5.2.1 Geophysical interpretation: Northern section - Fluvial features

The investigation of the area has revealed several large fluvial systems that show some

sinuosity. The most prominent of these main fluvial channels (the Shotton River channel

(Gaffney *et al.* 2009), see Figure 5.1) is over 600 metres wide, has been traced for a length

of 27.5km, and is located at the most northerly extent of the study area. The width of the

flood plain makes the river channel a very substantial feature within the landscape. Given

163

the poorly consolidated nature of the substrate and the high sand content of the Holocene

sediments, which would result in river banks with low cohesive strength, such a channel is

not impossible (Parker, 1976). On further observation, through the use of the opacity

rendering techniques and 2D Gauss data (see Figure 5.2), it is clearly apparent that the

image within the 3D seismic data actually represents the floodplain of the fluvial channel.

The actual palaeochannel contained within this, as visualised by the alternative techniques,

is much smaller at ~70 metres. The channel is also seen to possess a variety of tributaries,

one of which shows a pronounced dendritic pattern.

This feature is strikingly similar to those observed by Salomonsen and Jensen (1994) in the

Danish sector of the North Sea, in both size and morphology, which can be clearly shown to

have their origin in subaerial processes. The channel has overall morphology of a fairly low

sinuosity river and this, combined with poorly developed meanders, suggests that this is an

incised channel feature. The channel also shows a distinct similarity in morphology to many

Holocene meandering river systems such as the Rhine-Meuse delta (Törnqvist *et al.*, 1993)

and the Saskatchewan River-Cumberland Marshes region of Canada (Pérez-Arlucea and

Smith, 1999). The longevity of the channel form and course shown by the lack of meander

cut offs, suggests that the channel profile is relatively stable (Gibbard and Lewin 2003). This

is consistent with a relatively short period for fluvial activity within this landscape before its

eventual inundation.

The Gauss 2D seismic profile 90-5, obtained from the BGS, shows the internal fluvial

architecture of the channel, with its point bars clearly displayed (see Figure 5.2). The

correlation to the 2D survey is important as results available for the Danish section facilitate a correlation with the information from the same survey located directly over the "Shotton Channel". The 2D data from the Danish sector clearly showed that the channels observed in this study were very similar to the Danish fourth stage channels in morphology, stratigraphy and time location within the seismic data. This is significant, since borehole data from these features allow dating correlations to be made. Salomonsen *et al.* (1994) note that the channels from stage 4 date from the early Holocene, and, thus, the chronostratigraphic correlation allow an early Holocene age to be ascribed to the observed palaeochannels.

The 3D geophysical survey illustrates that, in this area, the Holocene channel is buried under approximately 16 metres of recent sediment. This is significant, as the bathymetry of the area shows that at this point there is a topographic high, possibly a sand bank (see Figure 5.3). This result illustrates the potential errors that are inherent with previous models which have utilised bathymetry as an analogue for the past landscape and further, demonstrates the usefulness of the approach outlined in Chapter 2.
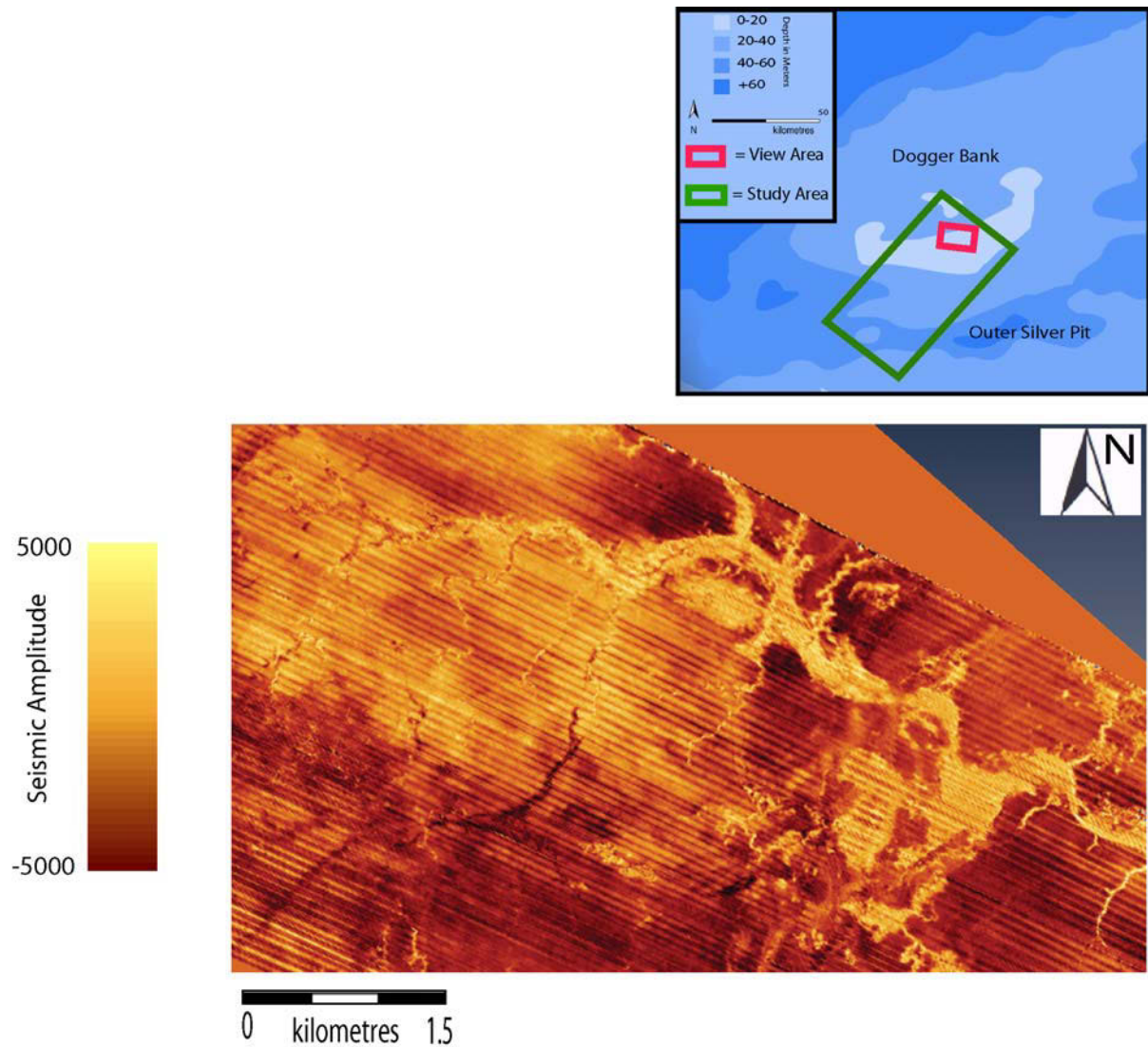
Figure 5.1 The Shotton Channel. The nature of the fluvial floodplain can be seen in this image. The small ovate shapes are interpreted as small lacustrine features.
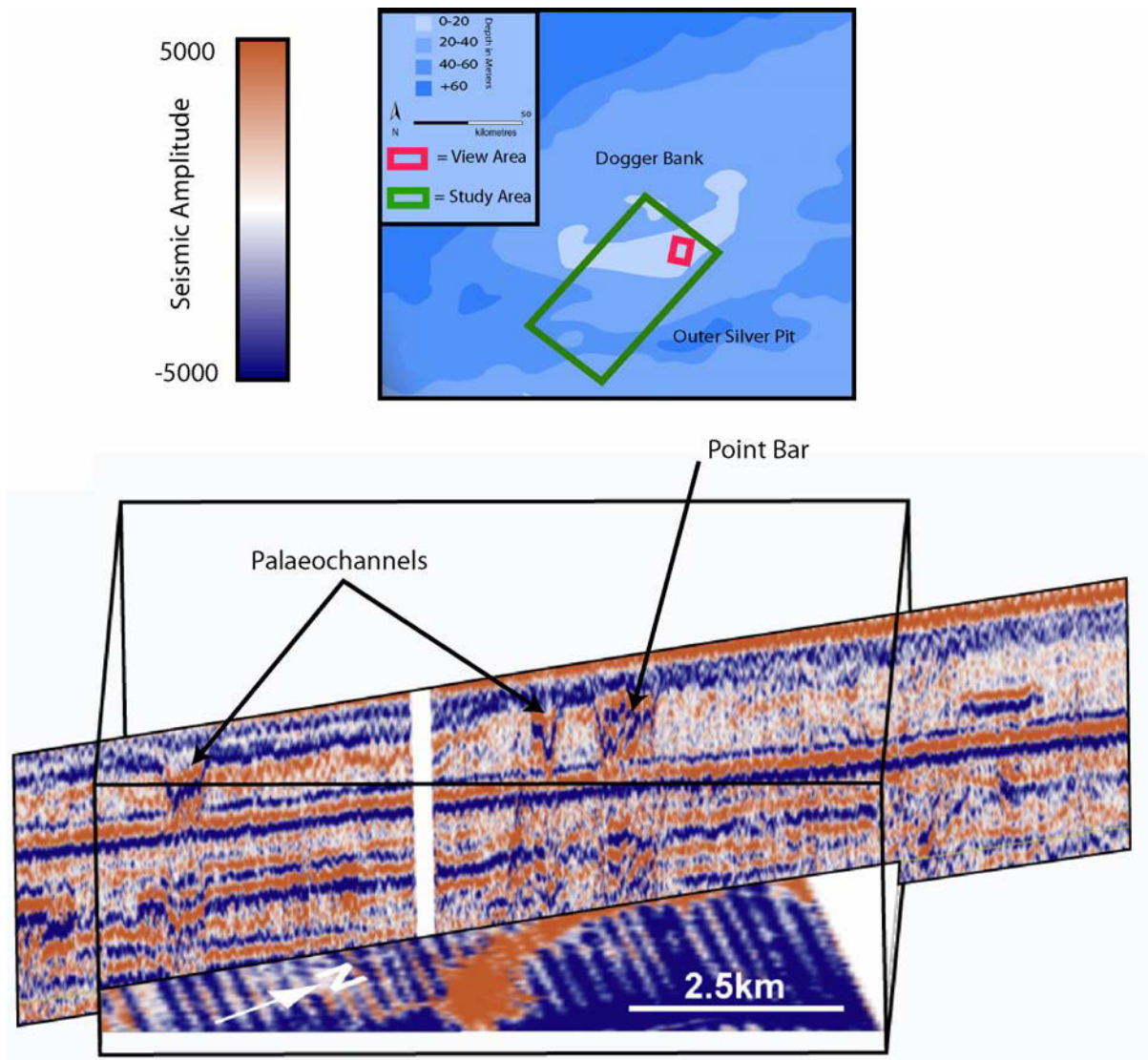
Figure 5.2 Gauss 2D survey overlain upon a 3D timeslice (0.076s) allows for the nature of the structure within the channel to be revealed.
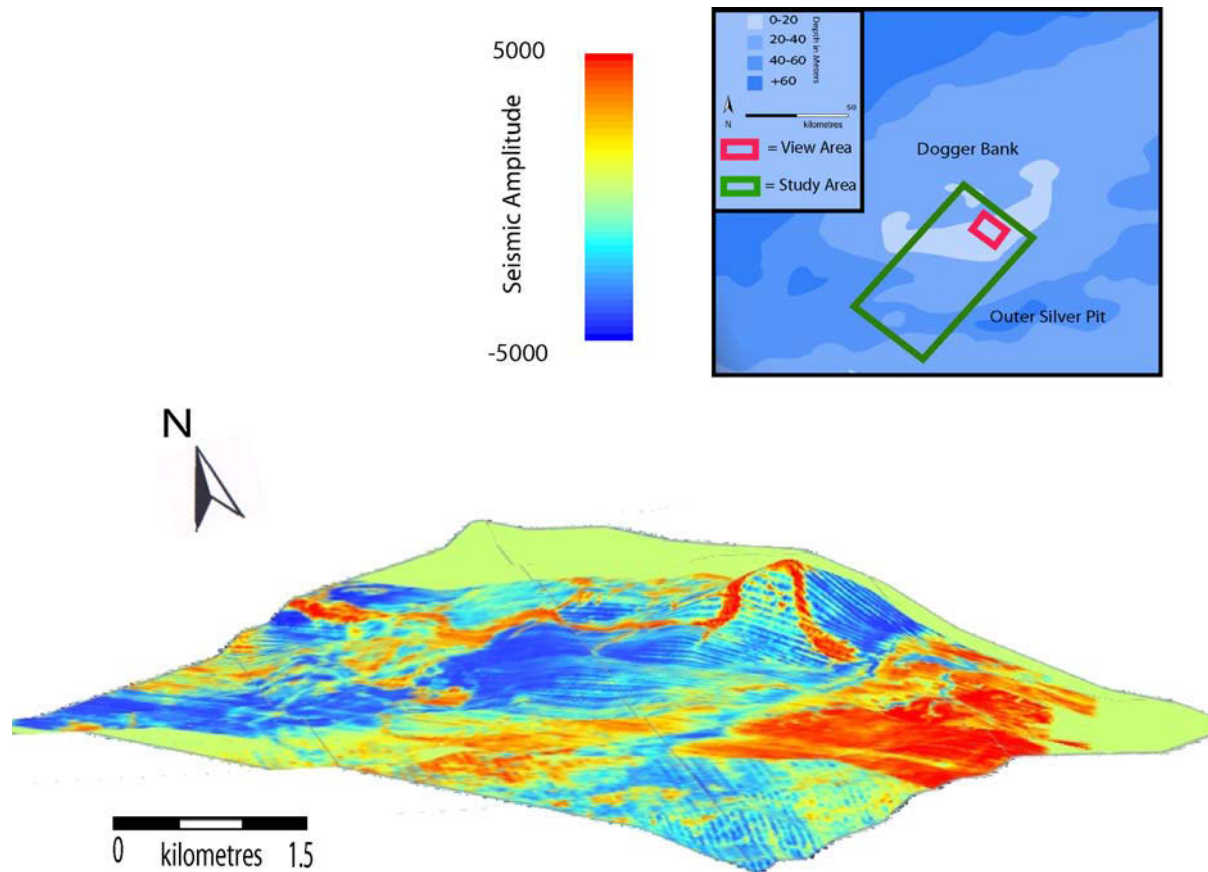
Figure 5.3 Timeslice Image (0.076s) of the Shotton Channel area draped over the local seabed bathymetry (from Fitch *et al.* 2005). It is apparent in this image that as the channel appears to run uphill in places, a landscape model generated from bathymetry would be erroneous.
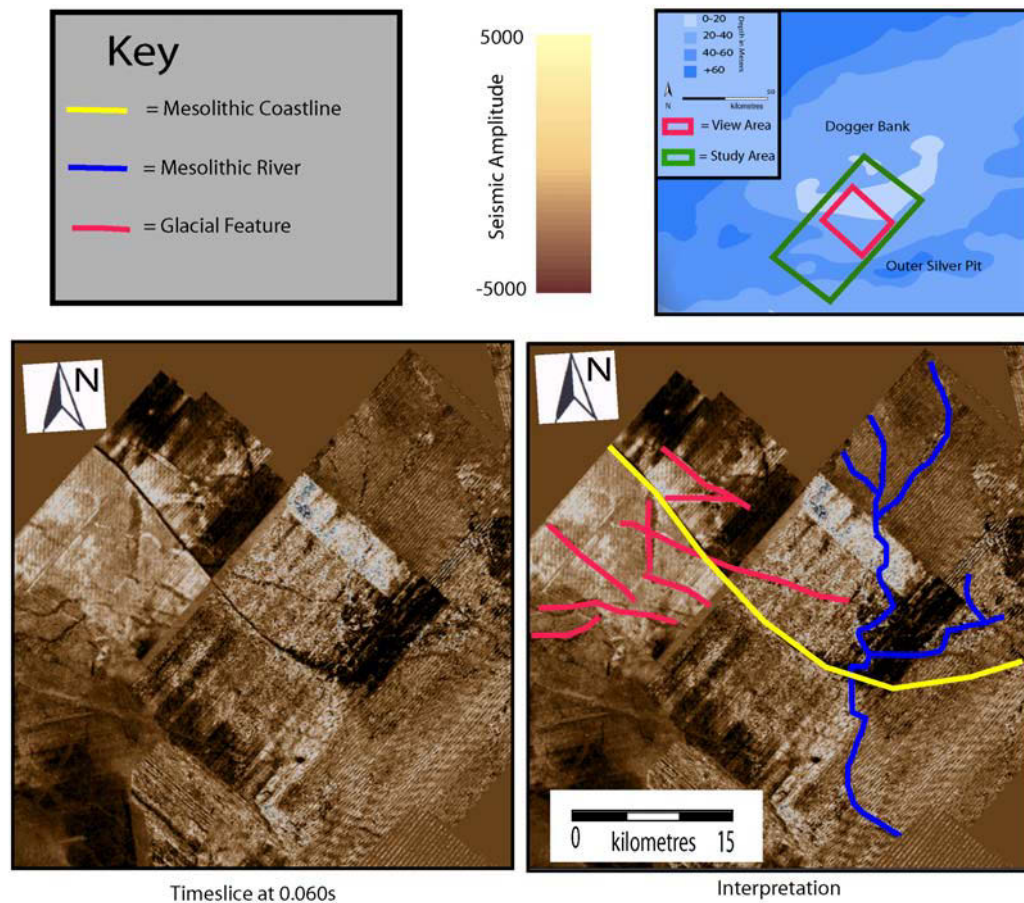
Figure 5.4 Timeslice (0.06s) Image of the Central study area. The interpreted timeslice shows the location of the Mesolithic features of interest.

5.2.2 Geophysical interpretation: Central section - Fluvial features

In the centre of the study area the data is affected by noise, which limits the ability to vertically resolve fluvial features. However, it was possible to locate the larger channels using serial seismic timeslicing (Figure 5.4). Within this central section, the predominant trend of all the fluvial systems is to the southeast. These drain the area of the Doggerbank, to the north, and converge on the Outer Silver Pit. All of the Holocene fluvial features can be seen to be incised into the underlying Late Pleistocene Doggerbank Formation. This

169

relationship demonstrates that these features are likely to have been latest Pleistocene or Early Holocene in date. The majority of these features are highly developed sinuous systems with a high stream order. Indeed, these systems possessed a much higher degree of sinuosity than observed in the "Shotton" channel. This increased sinuosity is almost certainly related to its position in the landscape, being in the lower lying and flatter regions and close to the shoreline. Under such conditions, the development of such sinuosity is not surprising. The geographic location of these systems in relation to the early Holocene topography suggests that they were sub-aerially exposed for a longer period than systems that may have existed in the Outer Silver Pit area. Additional landscape detail can be found in Appendix 3.

Further associated channels can be observed trending northwest to southeast, and most have some sinuosity, however, the interpretation is again limited by the noise. Fortunately, for this investigation the Gauss 2D line 90-6 runs through this area as well as through one of the larger channels. It was, therefore, possible to correlate these along the 2D profile as an aid to visualisation. From this, it was observed that the palaeochannel was strongly similar in both size and morphology to that of the Shotton channel, and thus it was inferred to have = formed under similar conditions to that observed for the Shotton Channel.

5.2.3 Geophysical interpretation: Southern section -Fluvial features

The south of the study area displays one of the most interesting fluvial features to emerge in this thesis (see Figure 5.5). Serial seismic time slicing clearly shows a large channel, of similar size to the Shotton channel, meandering northwards. The channels meanders increase in frequency as the channel approaches the coastline. The direction of this channel suggests that it may be draining the area around the Silver Pit in the southern North Sea (Appendix 3). This channel also possesses clearly defined dendritic feeder channels (see Figure 5.5).

What is perhaps most interesting is that this feature displays a response to sea level rise. The time slices clearly show a channel that proceeds down to the marine area, however, the volume rendering and opacity suggest a coastal embayment/estuary, which overlays and obscures an earlier and more deeply incised channel (Figure 5.5). This information shows temporality that can be provided by the use of 3D seismic data, as it is clearly discernable that this earlier channel was abandoned and buried by later intertidal deposits, thus illustrating the effects of sea level upon the archaeological landscape within this region (see Appendix 3). The estuary has a clear bathymetric expression within the BGS Digbath250 dataset, which suggests that this feature has not been fully filled by later deposits, and therefore any archaeological deposits may be near the surface.
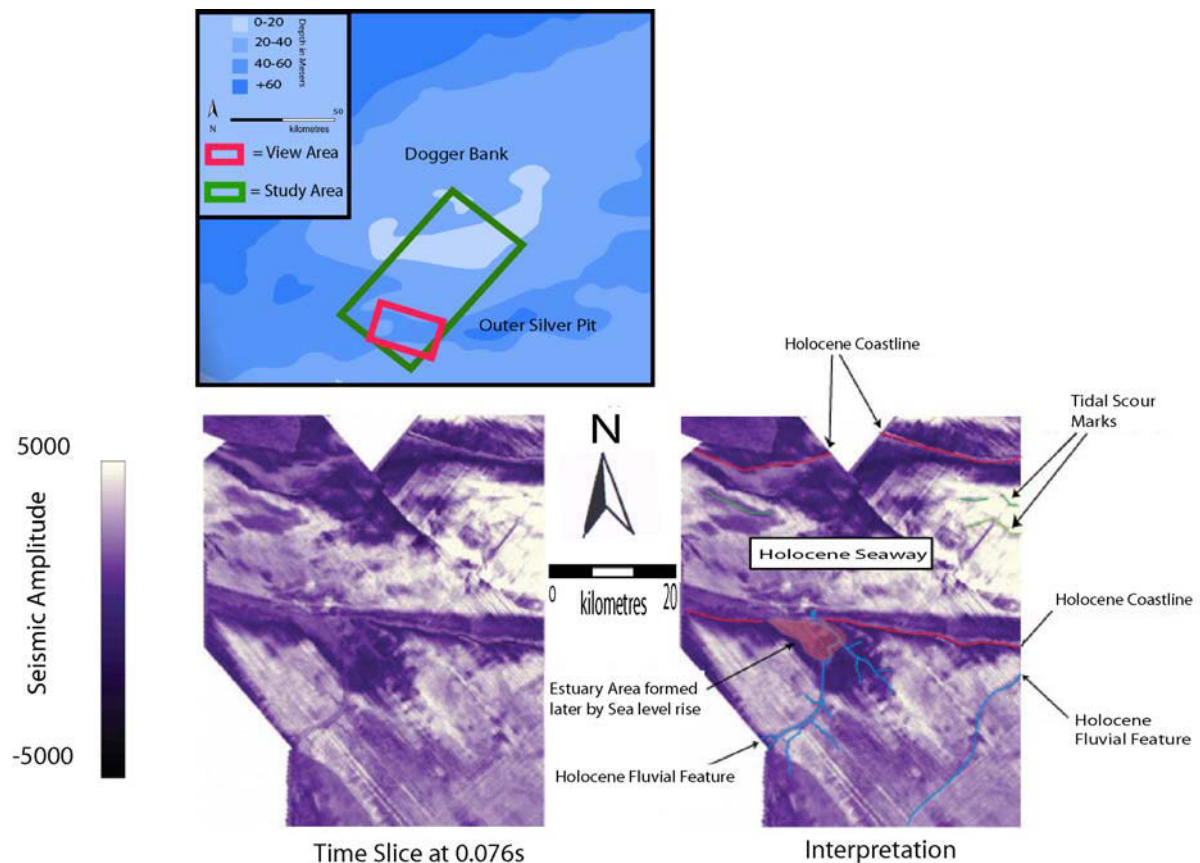
Figure 5.5 Images of the fluvial features from the south of the study area (from Fitch *et al.* 2007). The time slices clearly show a channel that proceeds down to the marine area, however, the volume rendering and opacity suggest a coastal embayment/estuary, which overlays and obscures an earlier and more deeply incised channel.

5.2.4 Geophysical interpretation: Possible wetland areas

Wetland structures have primarily been observed in the north of the study area, and are roughly 2km wide by 2km in area. These are characterised by their shape and irregular morphology as well as their relationships to the surrounding fluvial features (see Figure 5.1 and Appendix 3). These features often display small internal interdistributary streams. This morphological discovery suggests these are wetland/lakes into which streams flow and disperse, often reforming to produce outflowing rivers, and show a distinct similarity to the

Saskatchewan River-Cumberland Marshes region of Canada (Pérez-Arlucea and Smith,

1999). Indeed, published maps of the Saskatchewan River-Cumberland Marshes system

demonstrate a distinct similarity to the data described here with a major river channel of a

similar scale and sinuousity and associated lakes and minor channels (Pérez-Arlucea and

Smith, 1999). Closer to home, similarity can be seen with Quidenham Meer in East Anglia,

whose postglacial shape and size is comparable. The analogy is also useful as this Meer also

has a substantial input from a fluvial system (Bennett *et al.* 1991).

These Holocene wetlands have been located in the area immediately surrounding the past

location of a buried Weichselian tunnel valley, and this location may be no coincidence

(Fitch *et al.* 2005). It is possible that the fill of the buried tunnel valley acted as a

permeability barrier, thus allowing for poor drainage conditions that would favour the

formation of wetland areas, and/or these features may have also formed as a response to

sediment compaction within the tunnel valley fill. However, this remains uncertain.

5.2.5 Geophysical interpretation: Coastal zone

The investigation of the seismic data of the southern sector of this study revealed a large

depression located within data block J07, which correlates with the marine depression

known as the Outer Silver Pit (Appendix 3). It would have certainly represented a marine

channel during the marine transgression of the Holocene, and this supposition is supported

by the seismic data.

The use of volume rendering (see Figure 5.6) allowed a visualisation of the marine inlet that

formed the main feature within this region, and, with the combination of the attribute data,

allowed for an interpretation of this coastal zone. What is readily apparent from this is the

scouring of the base of this channel (see Figure 5.5 and Appendix 3). This evidence from

the 3D dataset is supported by the available 2D seismic data, which clearly shows the

presence of these scour marks (Figure 5.7). What is particularly apparent is the absence of

Holocene deposits from this area, which would suggest significant tidal currents. The idea

of the Outer Silver Pit representing a marine inlet had been proposed previously by Coles

(1998) and Flemming (2002) from the existent bathymetry. However, the extent and

morphology of the feature remained unresolved.
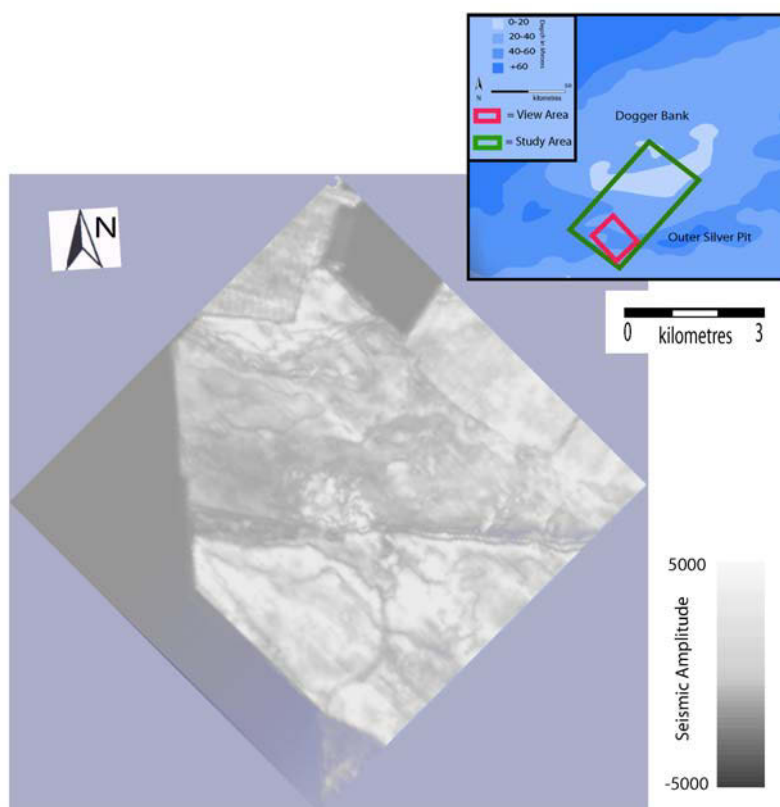
Figure 5.6 Volume rendering of the seismic volume (0 to 0.076s) of the marine inlet area.

The first evidence to support the existence of a marine channel in the Outer Silver Pit is the observation of the truncation of rivers at this zone. This is not, however, purely an erosional relationship, as the existence and correlation to the previously observed estuary shows. The fact that fluvial channels cannot be cross correlated on either side of the depression shows that this depression was obviously a pre-existing structure, and not a later feature. This suggests that these fluvial channels were flowing into the Outer Silver Pit area, and thus the activity within this structure dates from at least the Early Holocene. It has also been suggested that such a depression may have formed a lake in the earliest Holocene (Coles 1998), however, due to the heavy scouring in later periods, any lacustrine deposits that may have been present within this region are likely to have been removed.

The Outer Silver Pit has long provoked discussion over its mode of formation. This, the largest of the offshore depressions of the North Sea, has largely been thought by geomorphologists as having been formed during the glacial period, and thus represents a partially unfilled tunnel valley (Balson and Jeffery 1991, Praeg 2003). However, a different opinion is also present within the literature, with Donovan (1965) suggesting that early Holocene tidal currents were capable of eroding such structures. This was the preferred option of Briggs *et al.* (2007) who, after extensive examination of the geomorphic features and seismic records contained within the Outer Silver Pit, concluded that the evidence was "supportive of the theories of Donovan 1965; 1975 which suggest that strong marine currents were, at least, in part responsible in the formation of the Outer Silver Pit depression."
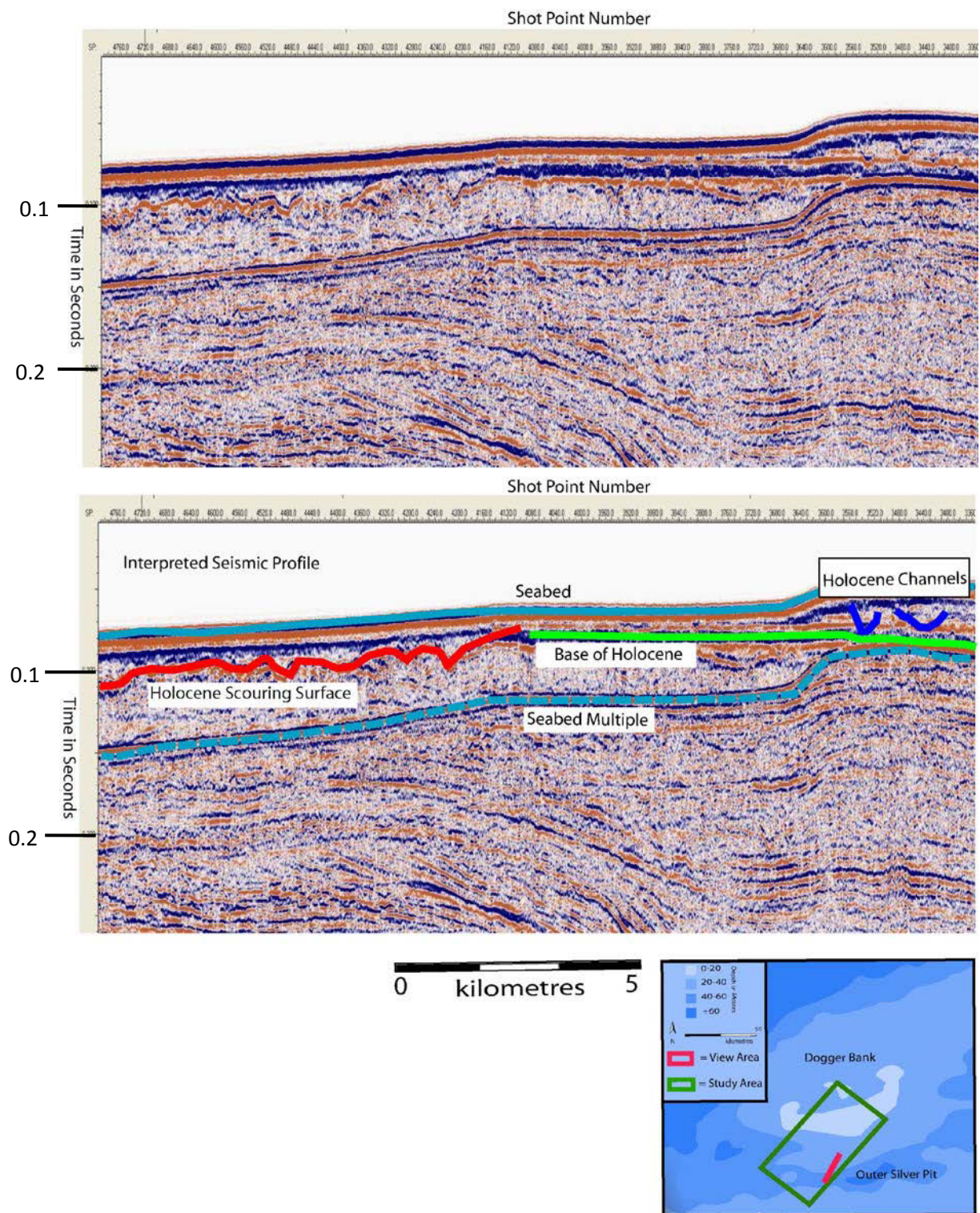
Figure 5.7 2D seismic profile across the Outer Silver Pit area. It is apparent in the interpreted profile that the Holocene layers have been removed, and the pronounced scouring surface generated.

Indeed, the strong erosional truncation observed by Briggs, that provided part of this evidence, can also be seen in datasets obtained for this thesis. Both the Gauss 195B 2D survey, obtained from the BGS, and also 2D sub bottom profiling information over the Outer Silver Pit, from the University of Bremen, clearly show this strong truncation. Since this truncation occurs over a deposit known as the "Botney Cut Formation", which is dated to the Latest Pleistocene to/Earliest Holocene by Laramine (1989) , the law of superposition states that the truncation must be younger than this deposit, and, hence, must date at the very least from the Earliest Holocene. Indeed, interpretation of this truncation, observed in sub-bottom profiles and in conjunction with sediment sampling by Salomonsen and Jensen (1994), dates this truncation to the Early Holocene. Since glacial conditions and processes were no longer prevalent in this region, another explanation must be found. Briggs observes the evidence for large early Holocene sand banks, which provided her with the evidence that the Outer Silver Pit was clearly a tidally dominated macrotidal environment with a strong current.

This interpretation can be fed back into the seismic data, and allows for an initial identification of a possible coastal zone. The area identified as a coastal zone contains high amplitudes and a strong acoustic signal within the seismic data. This is interpreted as beach deposits (sands). This interpretation was also reached by Rokoengen *et al.* (1982), working near the Norwegian trench. Rokoengen discovered a series of beach deposits buried from 1 to 23 metres beneath the sea bed and ranging in age from 10,800BP to 12,500BP, which featured a similar high amplitude anomaly. The sea level models published by Shennan (2002) strongly suggests that coastlines observed in the data would have formed in the

period circa 9,500 to 9,000BP. This information was utilised within the GIS to produce an

detailed spatial map of coastline for this period, which was applied to the relevant data

layers during the course of the preceding methodology.

5.2.6 Geophysical interpretation: Temporal and spatial relationships

As observed previously, due to the three-dimensional nature of the seismic dataset, it is

possible to make several observations about the temporal relationship of the observed

features. However, given the problems of seismic multiples within the data, establishing a

firm chronology for the fluvial features is not easy. Basic cross cutting relationships, as

shown for the Outer Silver Pit, and their positions in time do provide a simple chronology.

A few modern features can be observed directly upon the seabed; These are observed in

the highest sections of the 2D seismic dataset, (see Figure 5.8). Further, their position in

the upper sections of the seismic section and their structure revealed that these features

were actual reflections of large sand waves on the seabed surface that are of recent origin

(Lumsden 1986).

These are the most recent geological features and relate to the Terschellingerbank

member. These modern deposits represent the products of more recent marine processes

in the area, post dating the Early Holocene marine transgression of the area. Although

these deposits are observed to form a thin veneer over the area, as shown in Figure 5.8,

accumulation within structures can produce important local thicknesses of these deposits

(Laramine 1989).
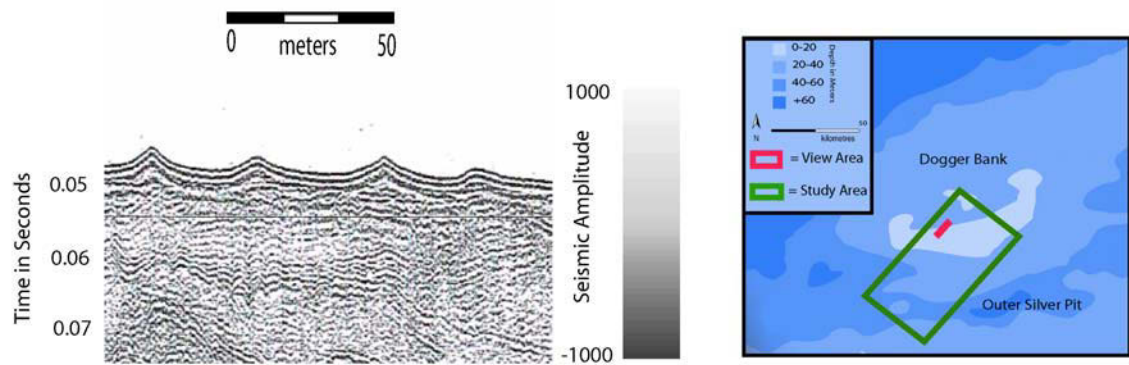
Figure 5.8 Modern Sandwaves observed within the thesis study area, which directly overlie the buried Holocene landscape.

The preserved Holocene landscape can be observed directly underling these recent deposits. Within this landscape, the fluvial features have perhaps the most interesting chronology. The Shotton Channel, when observed within the 3D seismic data set, can clearly be seen overlying a Weichselian tunnel valley and cutting directly into the earlier Late Pleistocene deposits. The Shotton River can be interpreted as post Weichselian as the tunnel valley has been filled and the river valley directly overlies this. As the buried tunnel valley has no visible effect upon the channel, it suggests that this feature has been infilled for a reasonable length of time. Indeed, had the tunnel valley not been completely filled with sediments it is likely that the river Shotton River would have reused the pre-existing tunnel valley. The Shotton River and its surrounding tributaries must, therefore, have occurred some time between the end of the last ice age (18,000 BP) and the Holocene, when the area was submerged (7000BP). However, it is possible to go further than this; If the position of the fluvial channels in relation to the seabed surface and the overlying

179

deposits of the Terschellingerbank member (Laraminie 1989 and Figure 1.3) are observed, it can be seen that the deposits associated with these channels almost certainly co-relate to the early Holocene Elbow Formation (Figure 1.3).

The Elbow Formation's fluvial and tidal flat deposits (Oele 1969) are reconcilable with such an interpretation. This determination is of considerable significance to archaeology, as the time period relating to the formation of these deposits is related to the emergence of this landscape and therefore likely to contain records of the human occupation within this region. Therefore, the Shotton Channel was a significant feature within the Holocene landscape of this region.

If the seismic reflectors from the seabed surface above the Shotton Channel and the reflector immediately beneath the base of the channel are mapped, it becomes possible to follow them from the centre of the study area to their confluence with the large central channel. The central channel can be seen to overlie the "base" reflector, and so is younger, whilst it is beneath the seabed reflector, and, thereby, clearly older than the present, chronostratigraphically establishing a relative age for this feature. Thus, by looking at the reflectors it is likely that the central channel occurred as part of the formation of the Elbow Formation, and is of roughly similar age to the "Shotton" channel (9,900BP ~ 9,000BP).

After careful observation, it can be seen that the southern channel suffers from a lack of reliable stratigraphic age indicators. However, it can be seen to overlie tunnel valleys of the Swarte bank formation, as well as being observed to be incised into the Bolders bank

formation. This gives an age of between the Elsterian (Swarte bank formation) and Upper

Weichselian (Bolders bank formation) respectively. Since the feature cannot be older than

the Upper Weichselian, and the channel is covered by the Holocene Terchellingerbank

Member, which is related to the Holocene marine transgression, it can be strongly argued

that this channel was an active part of the early Holocene landscape, and possibly even the

terminal phases of the Late Pleistocene.

Broadening the scope to include all the channels observed within the study area, it is

probable, given that their stratigraphic relations are the same, that all of these channels are

of early Holocene age. Although some minor cross cutting relationships can be observed,

the tributaries of the main channels of this region only record one period of incision. It,

therefore, is apparent that only one period of landscape emergence is recorded within the

geophysical data. This low level of landscape and fluvial system change within the seismic

data can only be really attributed to the relatively short period of landscape emergence

before this area was inundated.

Most estimates of the period of emergence give only around 4,500 years for this process

(Jelgersma 1979, Shennan 2002, Peltier 2004). The apparent lack of development of the

fluvial features observed within the dataset is consistent with this. There is, however,

enough evidence within the seismic data to suggest that the rate of sea level rise was not

continuous, but was in fact punctuated by periods of relative stability. The presence of an

estuary on the Outer Silver pit, and the clearly observable coastline suggests that sea level

rise halted long enough to allow the formation of these features. Although no direct dating

is available, cross correlation with the GIA data (see Chapter 2 and Shennan 2002) suggests that this feature was formed in the period 9,500 to 9,000 BP, and thus a period of stability may have been associated with this period.

The wetland areas have a broadly similar chronology to that of the Shotton Channel. They can be observed to sit within the same chrono-stratigraphic boundaries, and thus must date to a broadly similar time frame. Indeed, the fact that parts of these systems can be seen to intermingle with the main channel supports this proposal. Furthermore, these features can be observed to overlie the Weichselian tunnel valley, and hence post date these features.

The oldest features are a series of tunnel valleys that can be seen to underlie the Holocene landscape and cross the Outer Silver Pit within the south of the area. These features do not have any topographic expression, but are visible due to the ability of 3D seismic data to image through to the deeper deposits. Whilst these features are not relevant to discussion of the Mesolithic, they do have possible significance to earlier periods, as well as providing important chronostratigraphic points of reference. All of the observed features in the Outer Silver Pit have been directly related to features observed on BGS mapping ascribed to the Middle Pleistocene Swarte Bank Formation (Laramine 1989). Those underlying the Doggerbank area have been observed to relate to the Late Pleistocene Botney Cut formation (Laramine 1989). Due to time and focus constraints, only those features that were significant to the interpretation of the Holocene landscape were digitised.

5.2.7 Results: GIS layers - Landscape map arising from seismic interpretation

Upon the generation of seismic timeslices of the data within SMT Kingdom Suite, the information was exported to Esri ArcGIS 9.1 using the methodology outlined within Chapter 3. All interpretations were exported as AutoCAD DXFs to the GIS in a similar manner. The resulting timeslices were reconstructed within the GIS, and an example of this output can be seen in Figure 5.9. The resulting topographic data from the seismic picking was also exported and reconstructed (Figure 5.10).

From the initial examination of the seismic data, it was apparent that the seismic image can be interpreted in a similar manner to an aerial photograph. However, there are variable areas of visibility resulting from data quality (see Figure 5.9). This data variability was mapped within the GIS and the results presented in Figure 5.11. This is an important product, as it can be used to indicate the level of certainty with which the interpretation was made. Although the data was mostly of good or moderate quality, a fair proportion was of a lesser quality. However, it is perhaps a reflection of how good the overall quality of this dataset is, when lower quality data revealed the presence of larger channels. Despite this, the data quality was below a level at which smaller features (sub 250m) could be resolved. This is a result of data striping that is a product of the original data acquisition (see Chapter 3 for further discussion). Once the identification of the data quality was achieved, the interpreted datasets were included into the GIS. This information, in conjunction with the imported seismic imagery, allowed landscape feature polygons to be generated for the region. The result of this work is presented in Figure 5.12.

Since the predictive model required additional characteristics to be generated for the fluvial channels, these were categorised utilising the centreline technique (see Chapter 3). An example of the visual output of the generated stream ordering is presented in Figures 5.13 and 5.15. Analysis of these results provides the following information: It can be observed that for the channels observed within the thesis study area, the range is broadly consistent with results observed worldwide for the present day (86% of values being at Strahler order 1 or 2, see Figure 5.14), where 80 percent of rivers are of first or second order (Strahler and Strahler 1992). This is significant, given these figures are based upon floodplain data, and thus most of the Strahler stream orders are at best minima values.

The mean (1.52) and standard deviation (0.75) orders derived from the results also concur with this result. Shreve channel orders produced a range of values, which varied spatially. However, when visualised as bulk categories, the figures give a similar picture to that observed with the Strahler results (see Figure 5.16). The standard deviation (7.23) and mean (3.64) reflect the wider spread of the results, but in a categorised view, broadly reflect the results of the Strahler stream ordering. When observing the bifurcation ratio for these fluvial systems the average ratio is 3.8, which falls within the average ratio for modern streams (2 to 4) (Strahler and Strahler 1992).
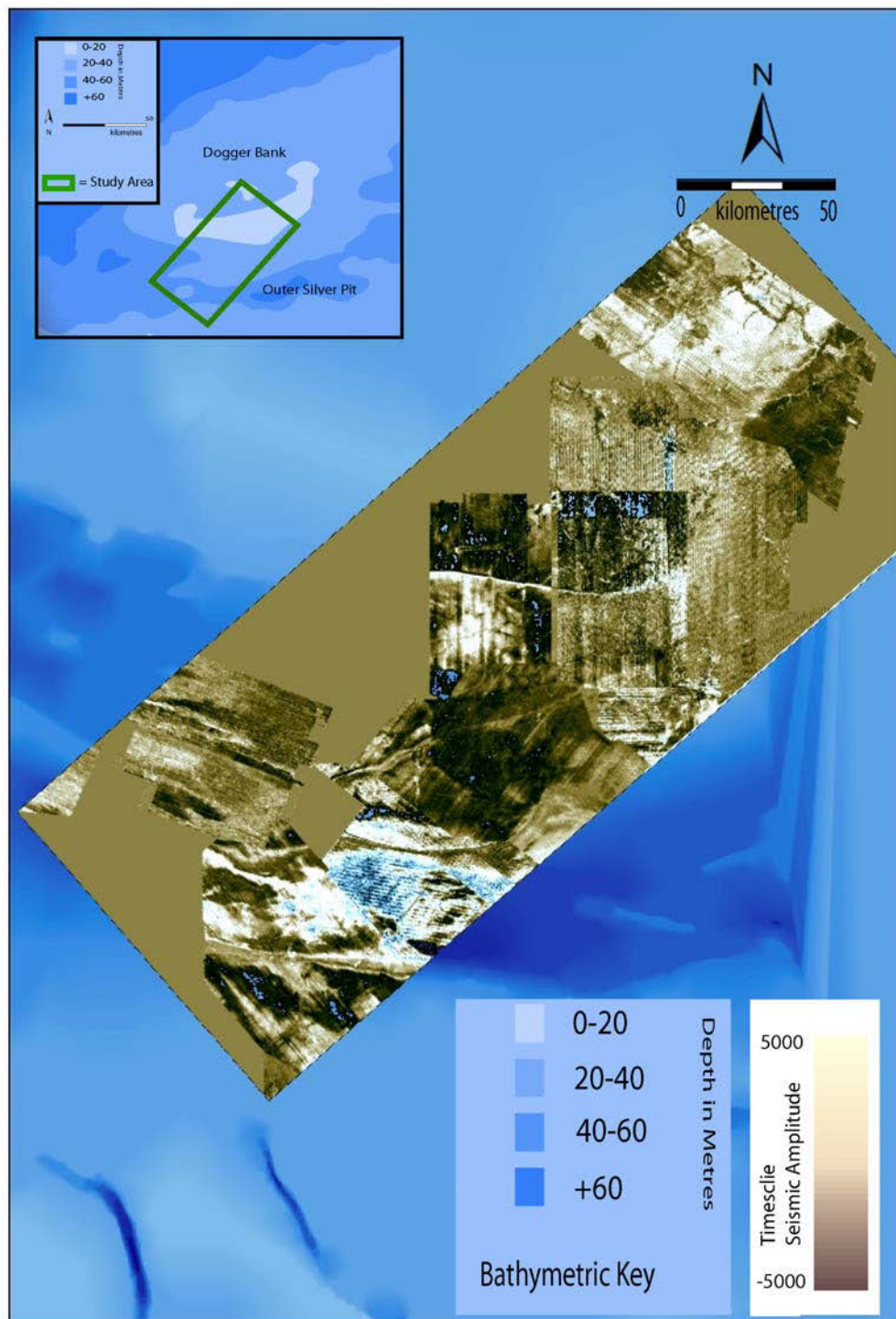
Figure 5.9 An Amplitude timeslice across the study area (0.076s) within the GIS.
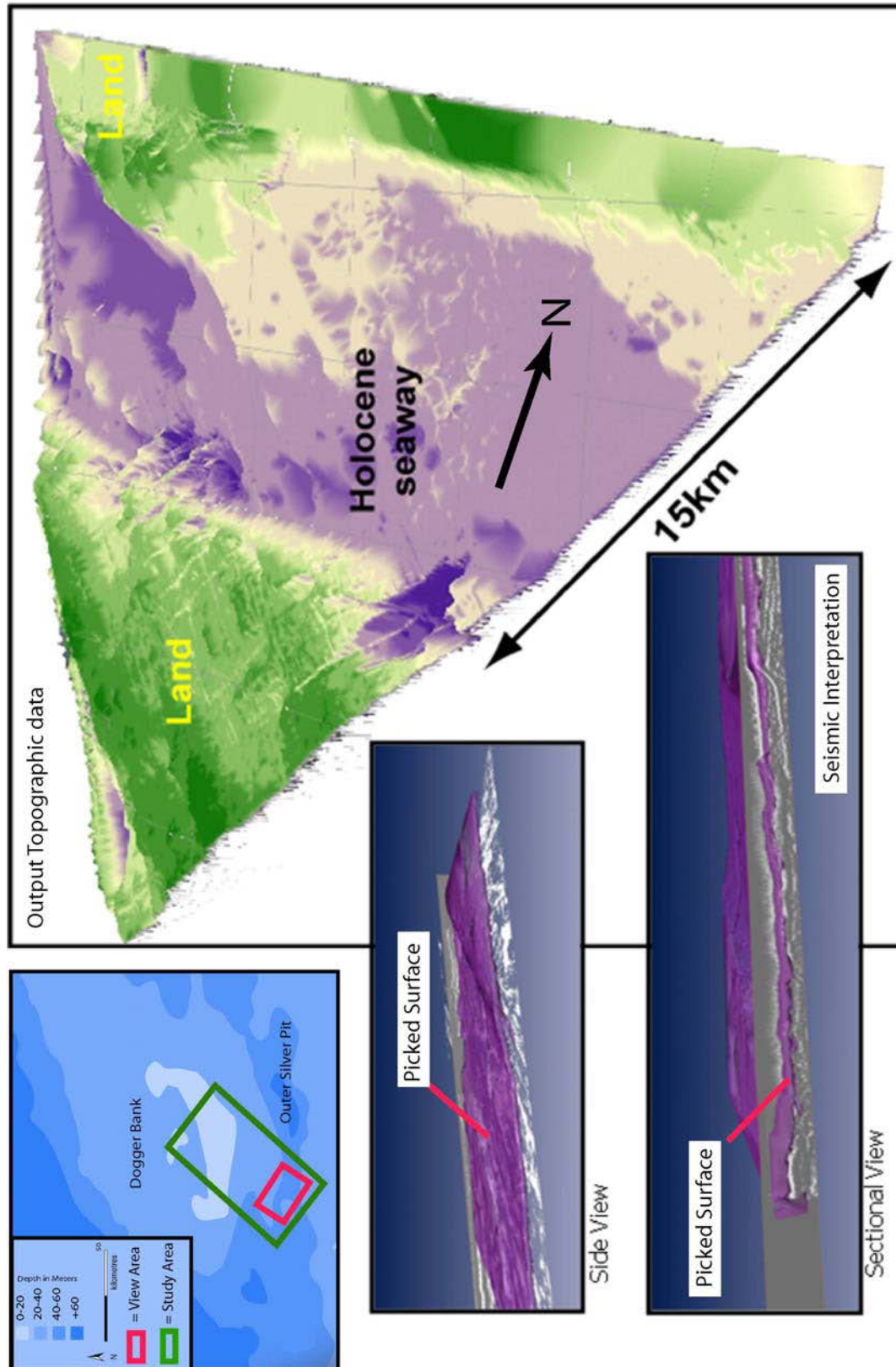
Figure 5.10 Seismic landscape surface picked from the seismic volume (side and sectional view) the resulting output data is then converted into a topographic model.
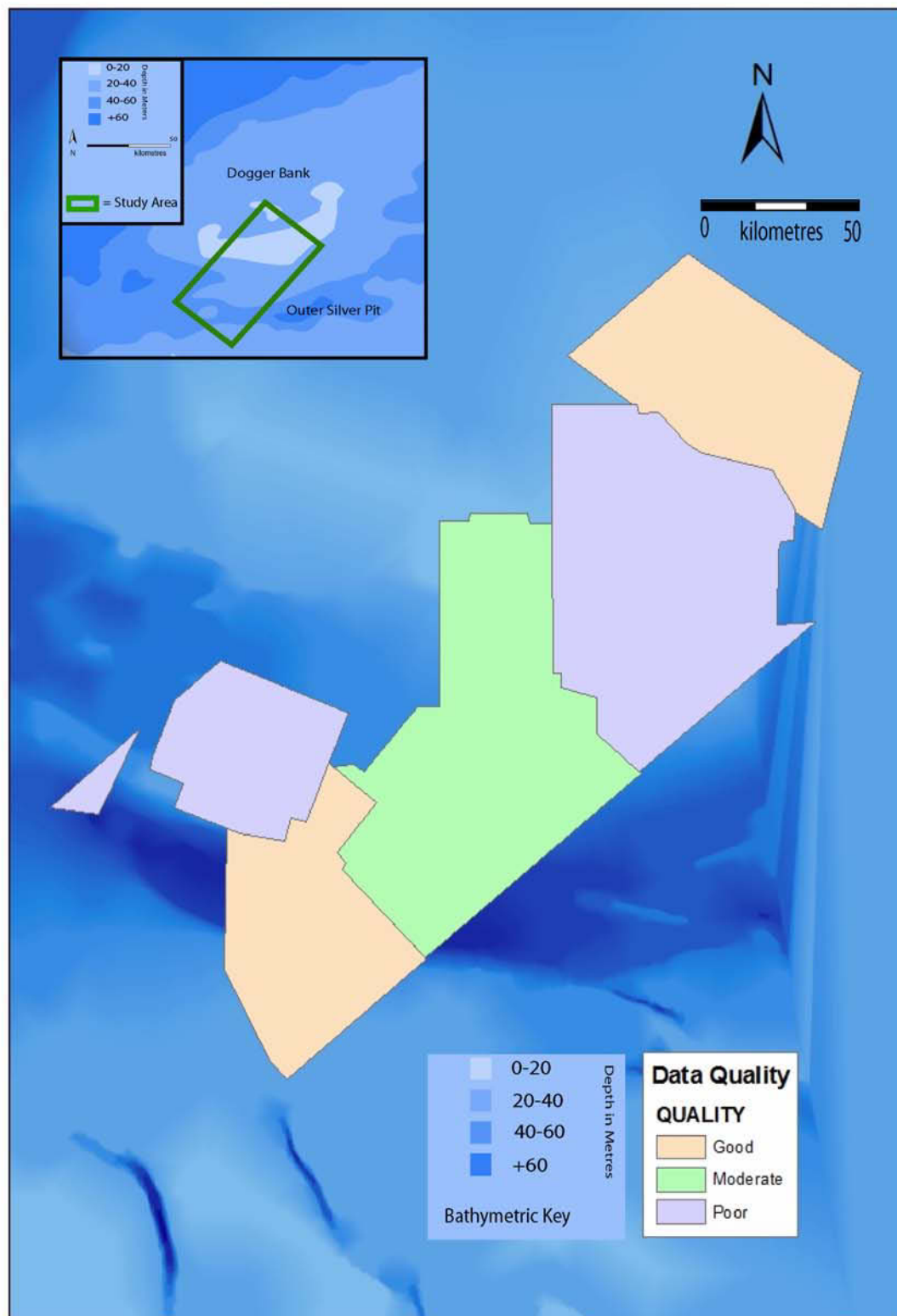
Figure 5.11 Map of the data quality for the top section of the seismic data.
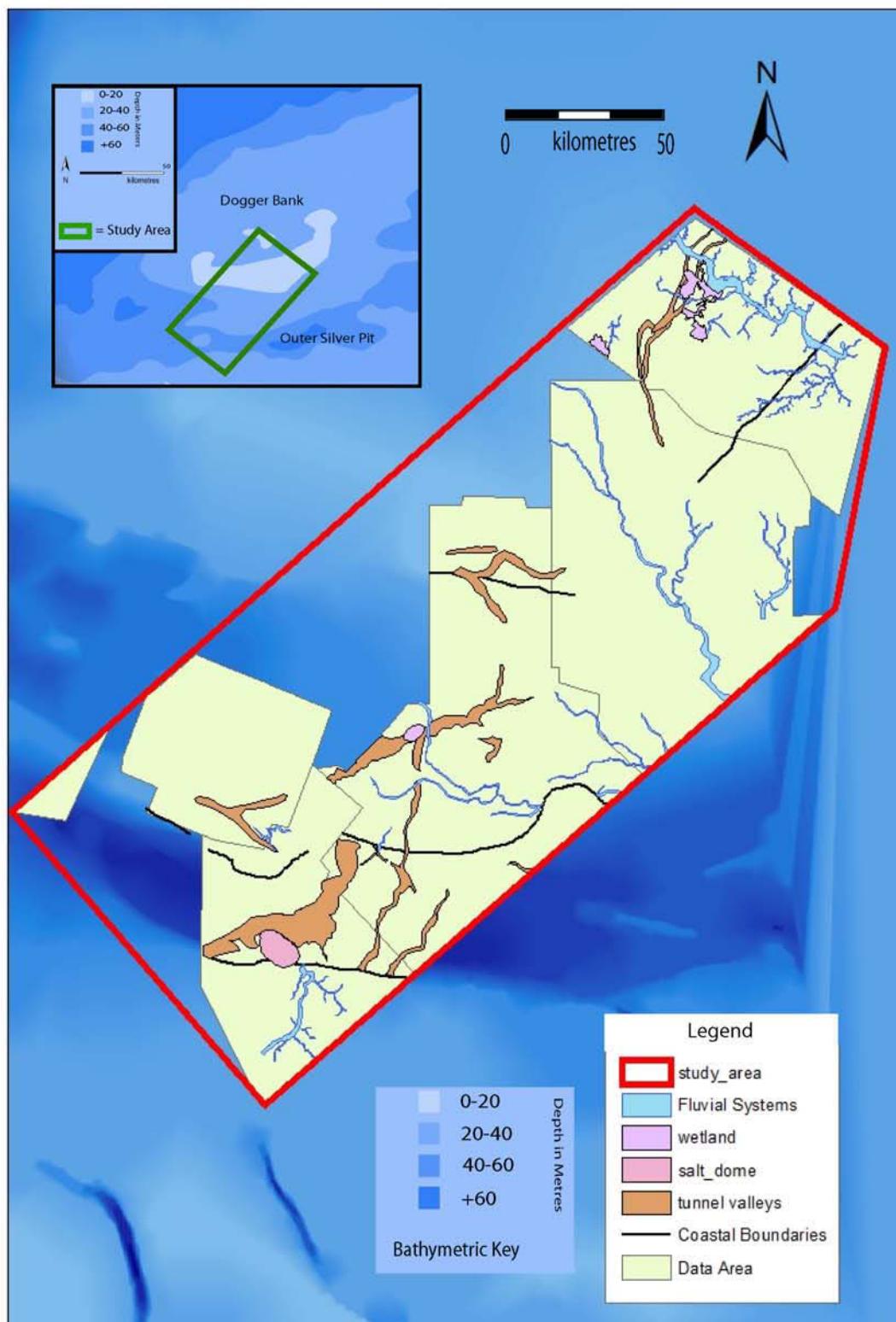
Figure 5.12 Landscape feature map for the study area.
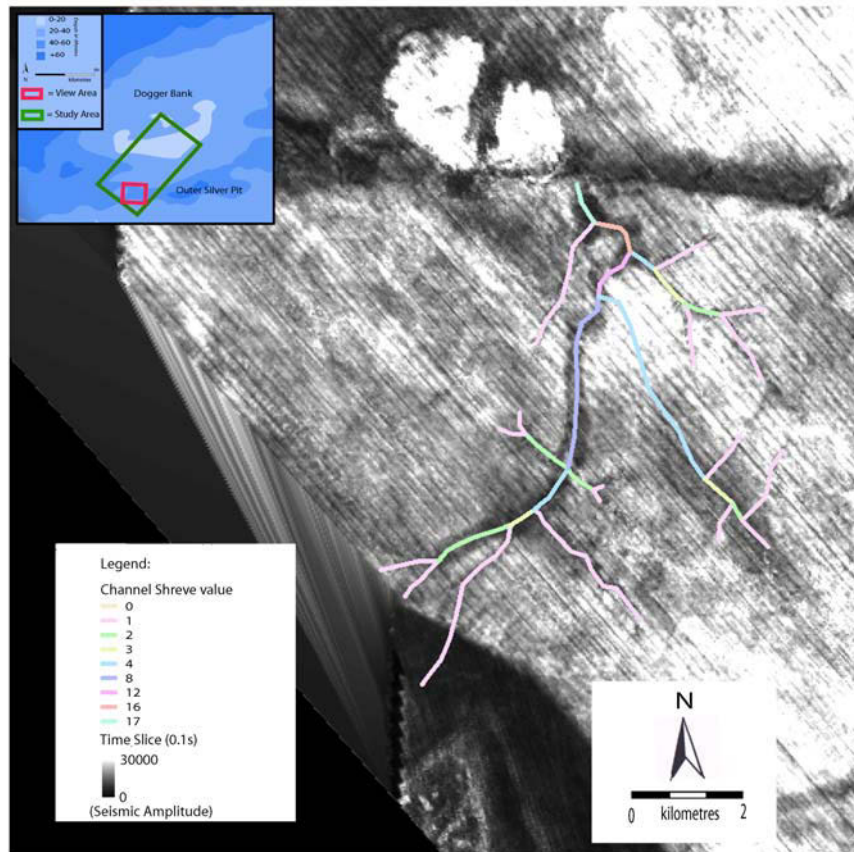
Figure 5.13 The generation of Shreve stream ordering for the identified fluvial systems. The channel is broken into segments within the GIS and scored using the Shreve ordering system.
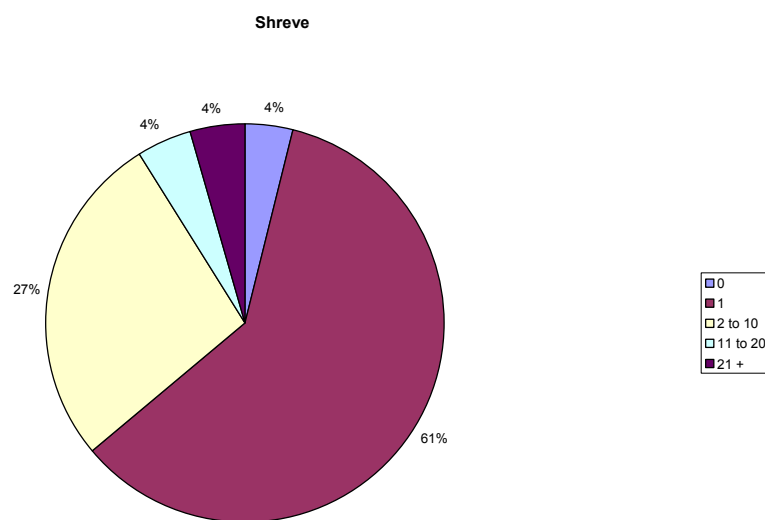
Figure 5.14 Percentage of streams in each Shreve order within the study area
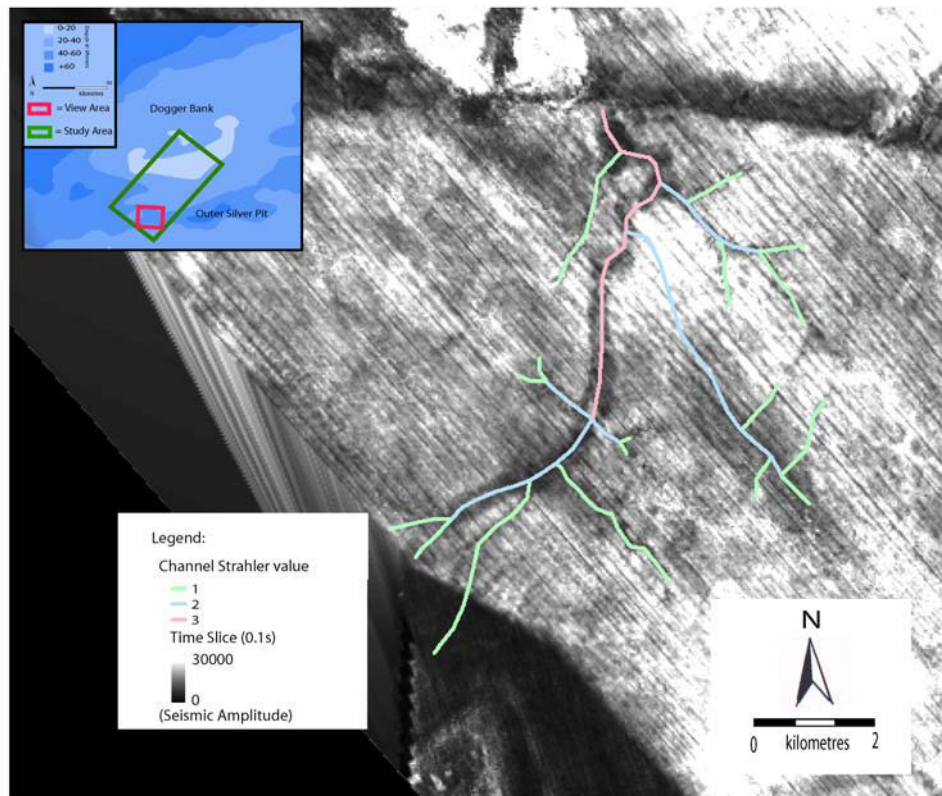
Figure 5.15 Strahler stream order for the same area as Figure 5.13. Again the channel is broken into segments within the GIS, but this time scored using the Strahler ordering system.
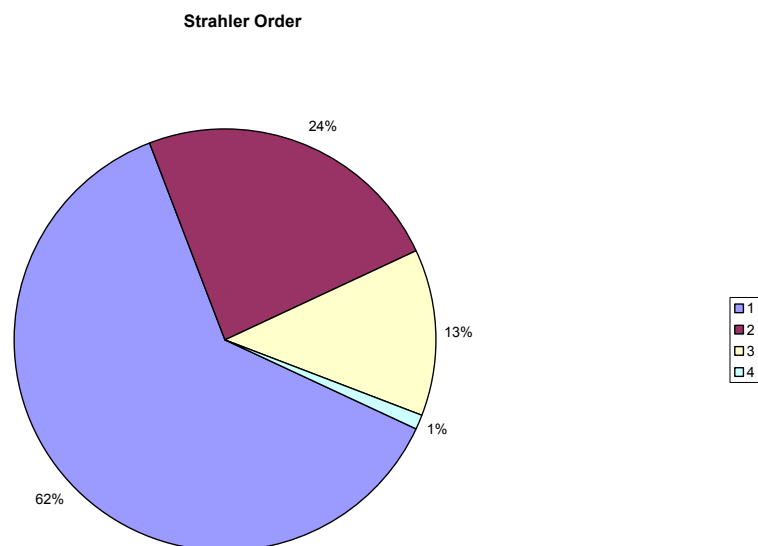
Figure 5.16 Percentage of streams in each Strahler order within the study area

5.2.8 River classification

To provide further information on the nature of the rivers within the GIS system, the sinuosity of each system was determined utilising the formula derived for this purpose by Leopold *et al.* (1964). A range of sinuosity figures were obtained for the regions' fluvial systems. These fall into three distinct groups. The first of these systems are those which score a lower sinuosity score of between 1.0 and 1.1. These systems tend to occur in the south and east of the study area, in the zones nearer the Holocene coastline. The second grouping has an average sinuosity of between 1.1 and 1.3. These are located around the Outer Silver Pit region. The third grouping includes systems with a high sinuosity (1.5 to 1.6), and are located in the extreme north west of the study area on the Doggerbank. It must be observed, however, that the sinuosity of these systems is expressed as a minima figure, since most of the fluvial features imaged by the seismic data are the floodplains. It is therefore extremely likely that the actual sinuosity figures could be higher.

The channels were then classified using Rosgen's (1994) classification system (see Figure 3.11). It was observed that that the three groups again reflected three different types of system. The first low sinuosity group was classed as stream type "D", that of braided systems, whilst the second group of intermediate sinuosity was classed as anastomosed systems (category DA). The final category of highly sinuous rivers was classified as C category, that of meandering systems. Whilst caveats still apply, because of the use of minima figures, it is interesting to observe that the channels with the highest observed sinuosity are those related to areas which represent the last stages of landscape formation

before inundation. It is likely, therefore, that these higher sinuosity features were a product of the extended time taken to evolve a complex floodplain system.

5.2.9 Generated soil map

Due to the submergence and burial of the Mesolithic landscape of the southern North Sea, there is a general lack of soil information that could be used for archaeological modelling. Given these difficulties, soil information must be derived by utilising other means. The seismic data provided the accurate spatial evidence, and source material information required. This was combined with geological mapping to produce a determination of the probable soil type for each parent material across the region and utilising the methods outlined in Chapter 3.

As the predominant parent material is glacial boulder clay, the most common soil type would have a wet basic soil. This covers almost all of the study area, apart from the area of fluvial systems, the Outer Silver Pit, and a small outcrop of chalk in the central part of the study area (Figure 5.17). Alluvial soils were widespread and their distribution is well controlled, using evidence from the seismic data.

Other minor soil types are also located within the study area. These only occur in small patches in the central zone; The most significant of these being a well drained basic soil. Although the Outer Silver Pit could have possessed a variety of soil types, due to inundation, the area is likely to have been submerged for most of the period of study. Additional complications to this have been identified as being caused by erosion from

marine inundation, which suggest that any pre-existing parent material may have been removed. Thus, the determinations based on the parent material may be incorrect. However, without further evidence the available data represents a best guess.

What is, perhaps, the most surprising result of this work, is the homogeneity of the soil types across the region. Given the wide distribution and common nature of the parent material, this, perhaps, should not be surprising. However, it is also likely that the seismic data, given its relatively course resolution may not identify minor differences in the boulder clay that could cause localised changes in soil conditions. As observed, the parent material is glacial in origin and is, therefore, likely to contain some local variations within the material from which it was formed (Cameron *et al.* 1992). These localised variations must have had some effects on the local soil type. However, the bulk of this material is broadly similar and this highly localised effect is likely to have little impact on broader results.
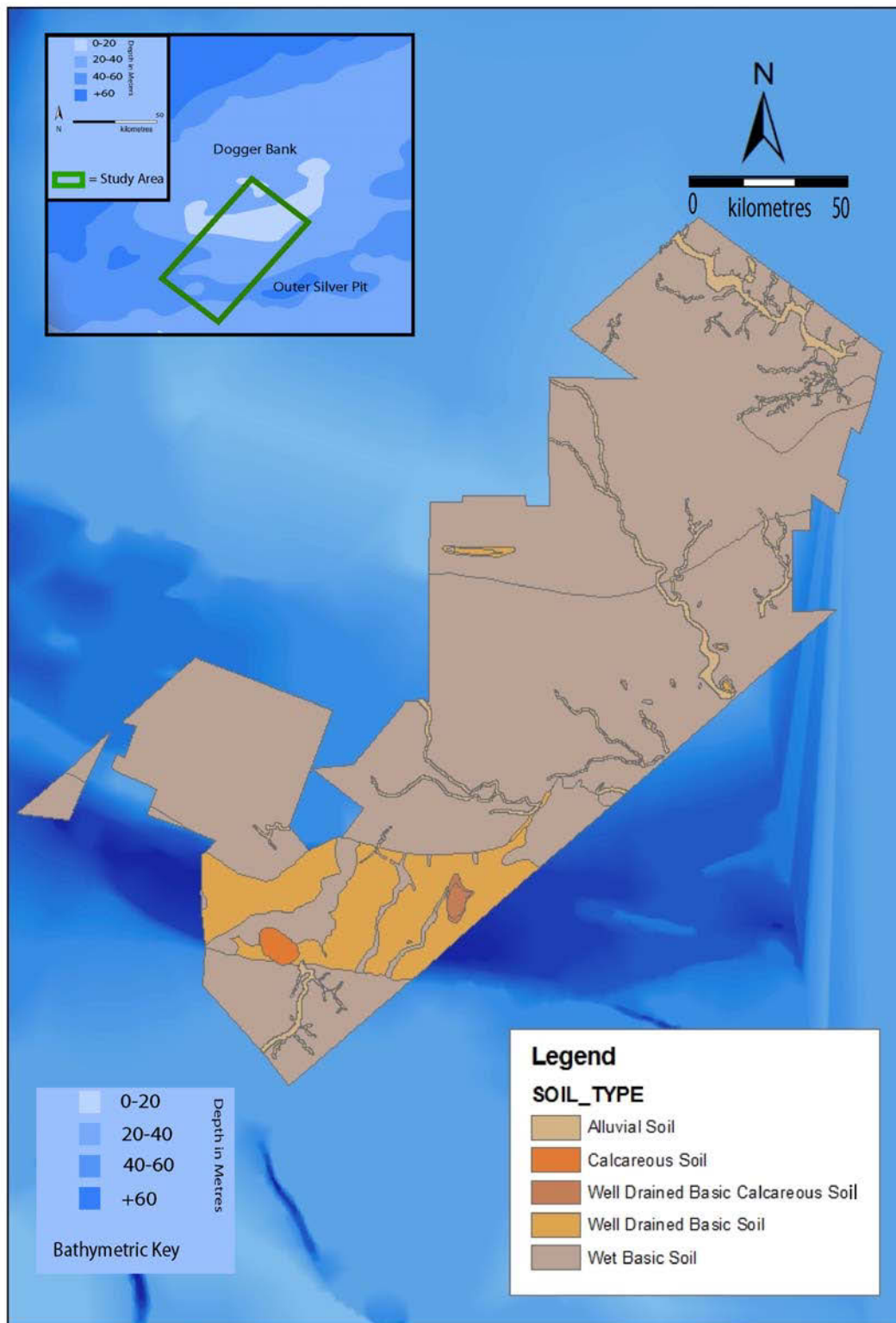
Figure 5.17 Generated soil type map for the study area.

5.2.10 Tree dispersal data

The soil data generated provides a useful base dataset upon which tree dispersal models can be applied. The Birks (1989) pollen isochrones and tree dispersal maps were, therefore, applied to the soils map (see Figure 3.12). Through the utilisation of this data, and the methodology outlined within Chapter 3, the dominant woodland type for each soil zone was determined from 10,000BP, the start of the Mesolithic, to 7,500BP, the last date that Shennan (2002) determines that the study area was sub-aerially exposed. The resulting maps were draped over the topographic data generated by the seismic interpretation. To illustrate the effect of sea level rise upon the vegetation, sea level information was applied utilising the information provided in Shennan (2002). This was performed at 500 year intervals between the chosen start and end dates (10,000BP to 7,500BP). A 500 year interval was chosen, as it was the resolution that best fit the sea level data and the pollen isochrones. The results of this mapping are presented in Figures 5.18 to 5.23, and will be discussed by period.

The results at 10,000BP show the woodland to be largely birch dominated (Figure 5.18). Some willow may be located locally in the alluvial areas. The presence of an Outer Silver Pit lake presents a possible problem. The level of this lake is not resolvable, due to later erosion. Therefore, the map represents this area without consideration of the presence of a lake. The homogenous nature of the dominant woodland is largely a product of the restricted number of tree species available during this period. Marine incursion of the region has begun at 9,500BP, and the Outer Silver Pit is inundated. This is shown by the

position of the red line in Figure 5.19. However, the restricted tree species still results in a very similar distribution to that of 10,000BP.

At 9,000BP (Figure 5.20) elm emerges in the area. However, it is important to observe that most favourable areas to elm are submerged at this period. Therefore, there are only a few pockets of elm dominated woodland which are significant. These are located in the central section of the study area and are restricted to localised "highs" in the landscape. Whilst these areas are small, they would have provided significant diversity in woodland which would otherwise be dominated by birch.

Circa 8,500BP, a major change can be seen in the woodland. The dominant birch woodland is replaced by elm and oak. Indeed, the oak Isochron can clearly be seen to bisect the study area (Figure 5.21). What is significant, however, is the fact that this change is reflected in the actual physical landscape. To the north of the study area, on the Doggerbank, the woodland is elm dominated. However, in the south of the study area, and on a small island on the flanks of the Outer Silver Pit, the woodland is oak dominated. The submergence of this region may, therefore, have acted as a barrier to oak spreading and, thus, facilitated elm to remain the dominant woodland type in the north of the study area. This would clearly affect the resource distribution between the two areas. By 8,000BP the maps predict that those areas not submerged are dominated by oak woodland. However, if we consider the result for 8,500BP, it is possible that elm dominated woodland remained on the northern islands. Without further evidence to support this, however, it remains speculation. Therefore oak woodland was selected as the dominant type for these areas. In

the final stages of the landscape at 7,500BP, almost all of the study area is submerged. On

the few isolated islands that remain where oak woodland remains dominant (Figure 5.23).
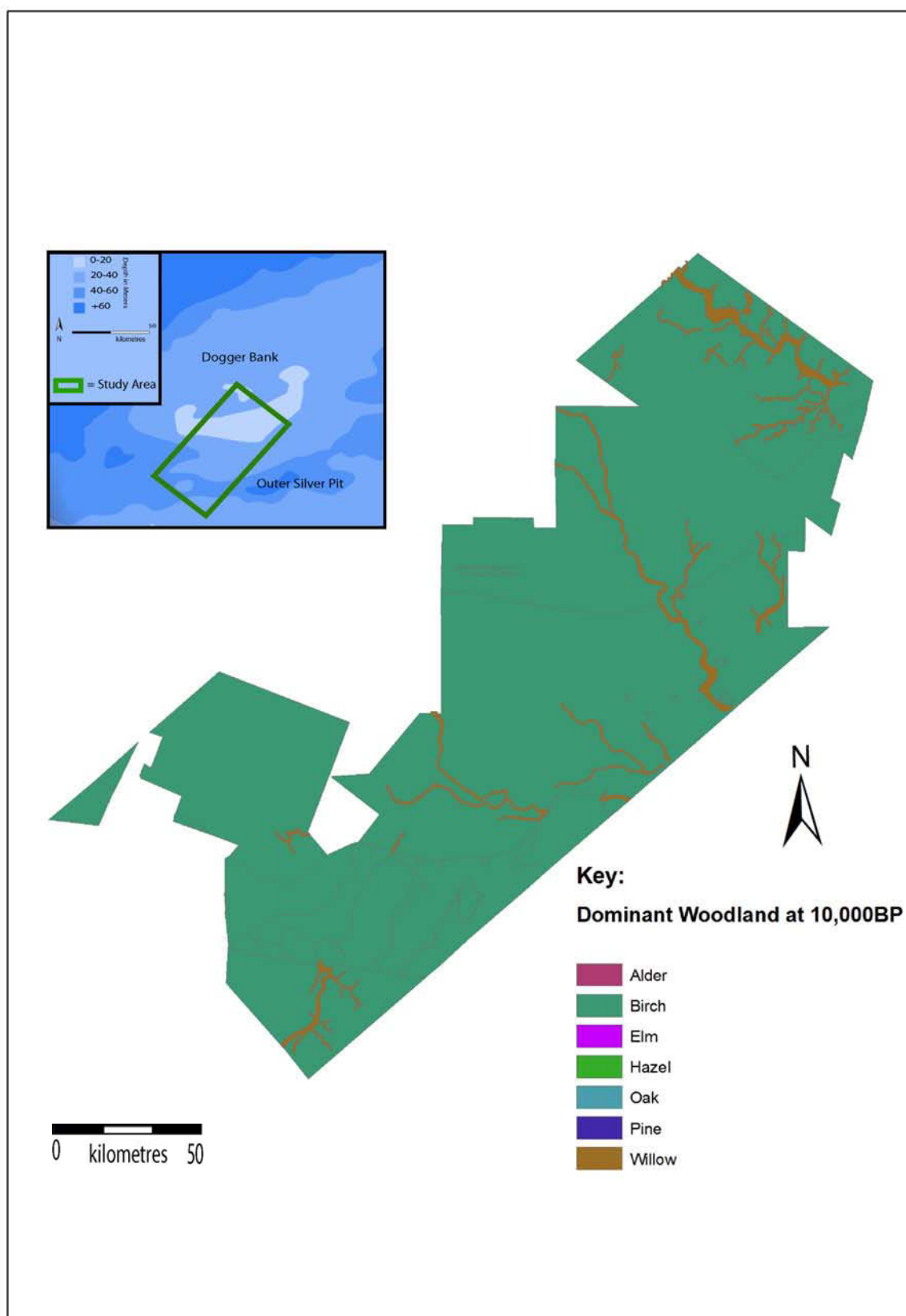
Figure 5.18 Dominant woodland map for 10,000BP
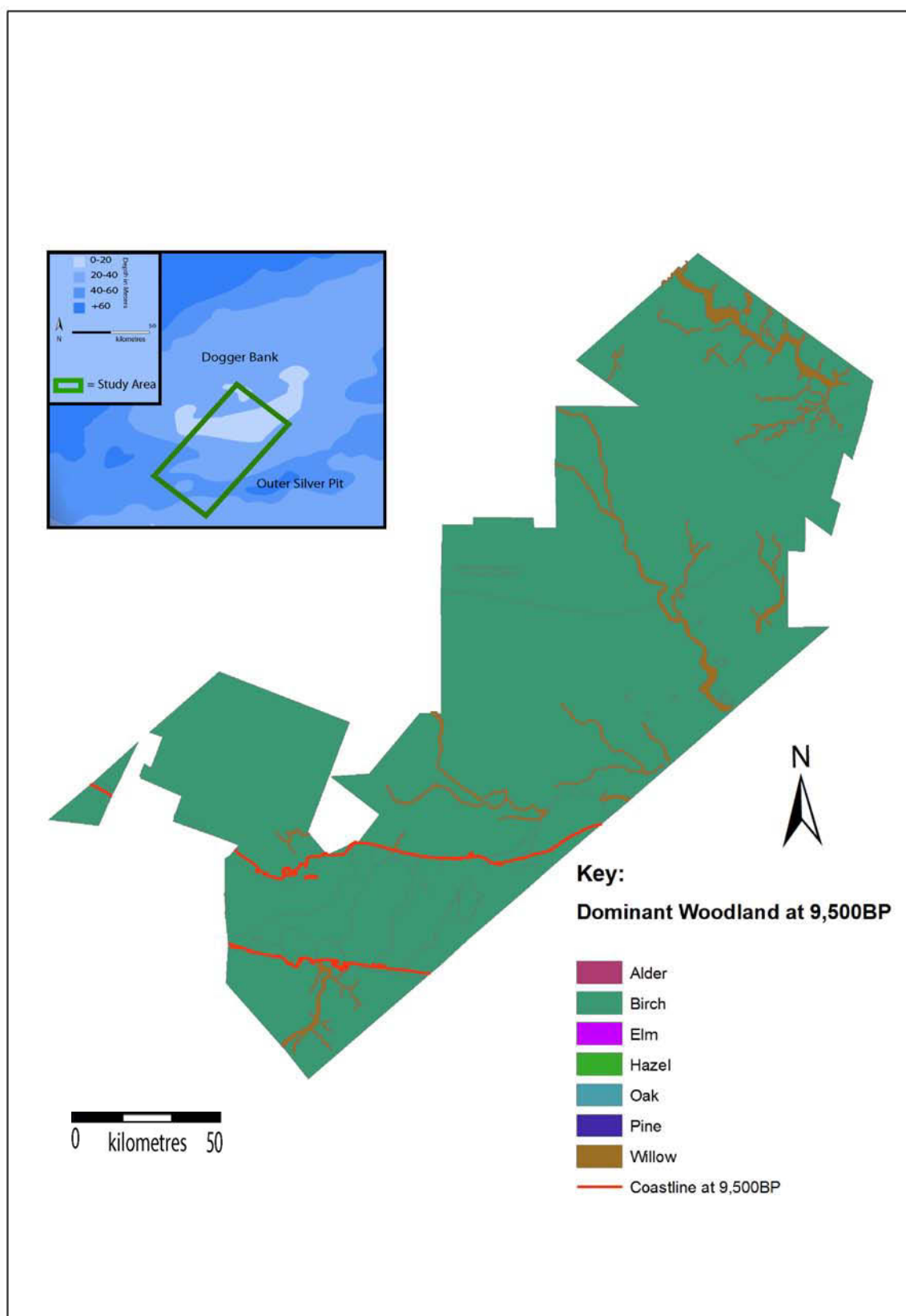
Figure 5.19 Dominant woodland map for 9,500BP (coastline in red).
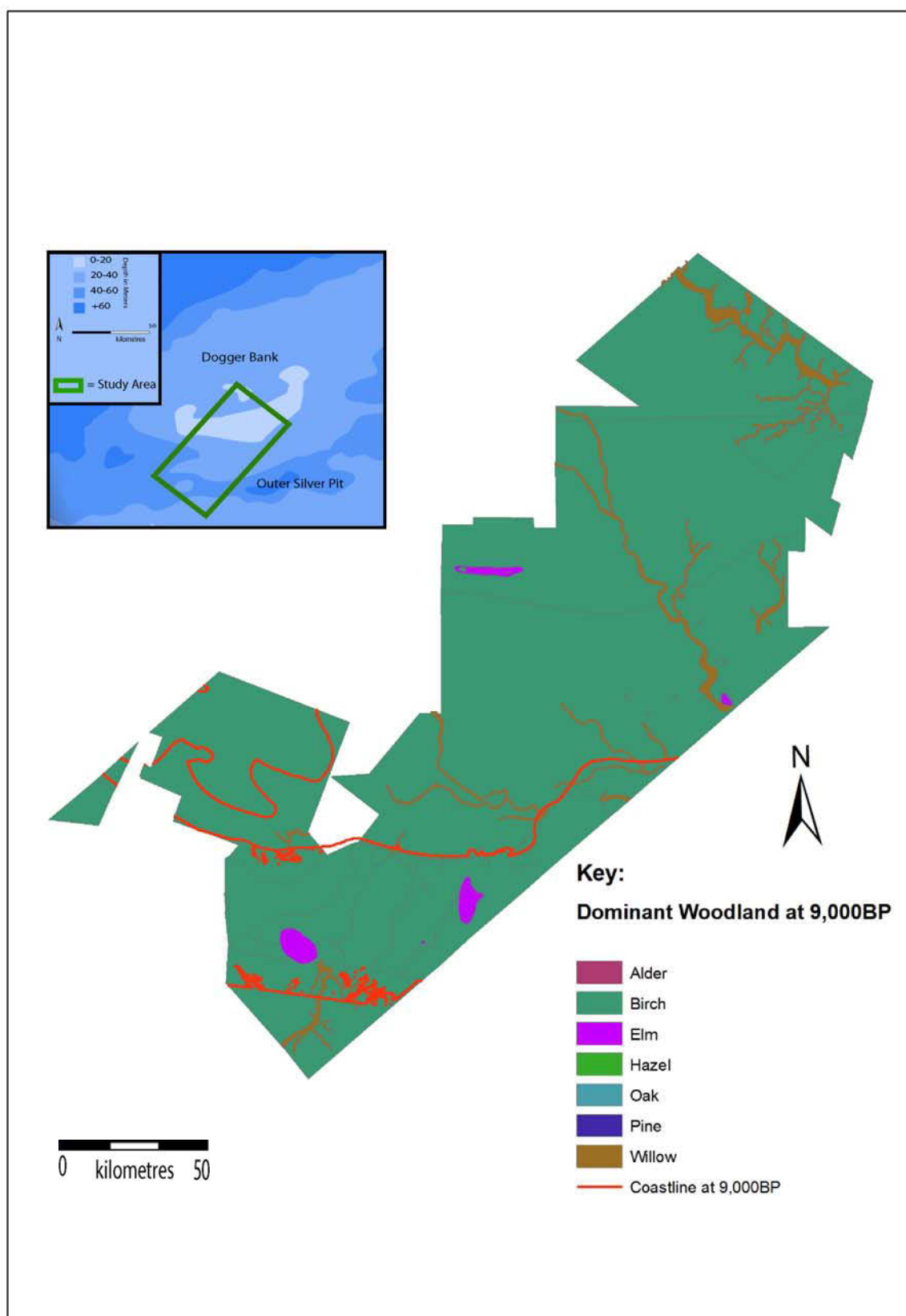
Figure 5.20 Dominant woodland map for 9,000BP (coastline in red).
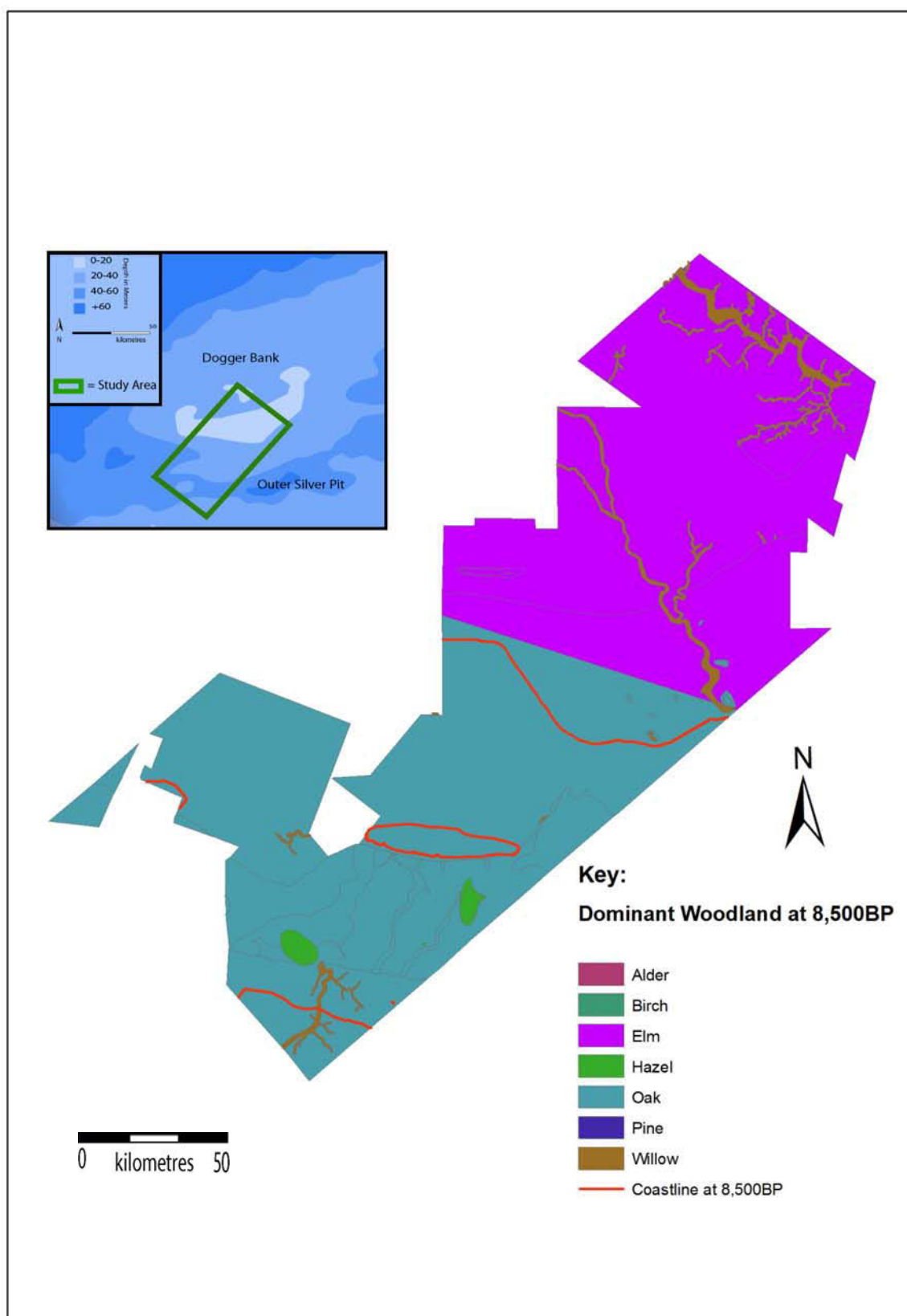
Figure 5.21 Dominant woodland map for 8,500BP (coastline in red).
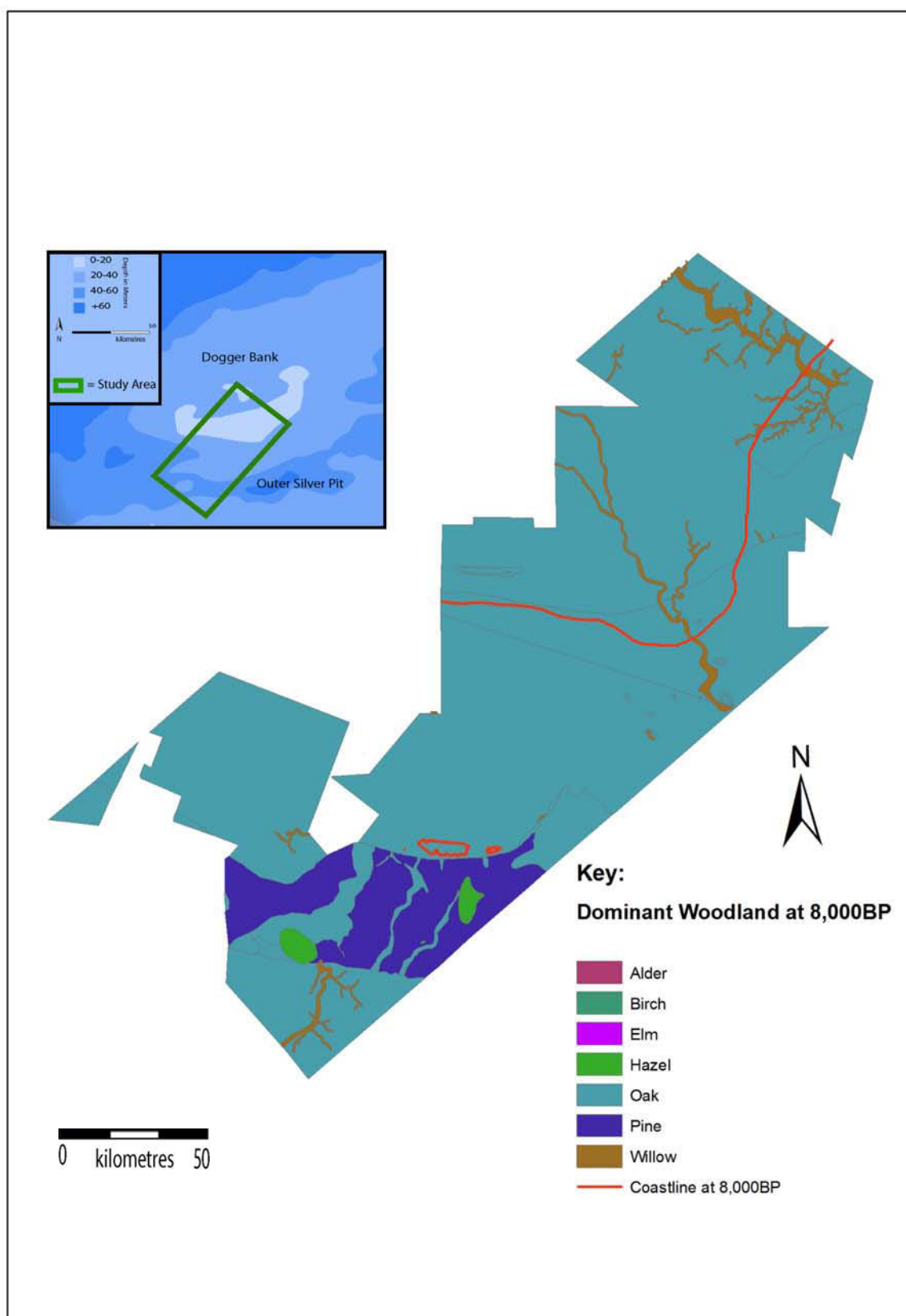
Figure 5.22 Dominant woodland map for 8,000BP (coastline in red).
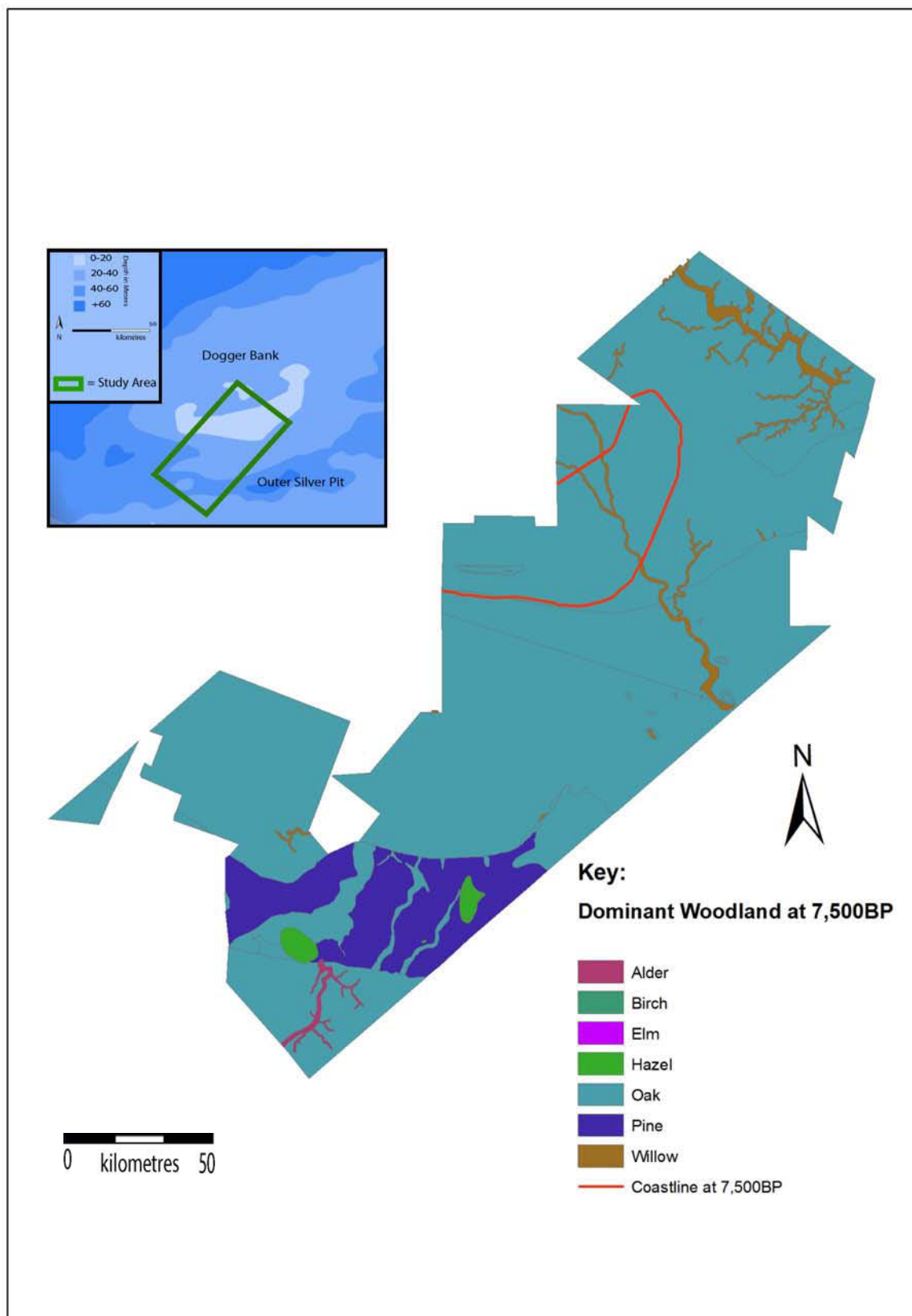
Figure 5.23 Dominant woodland map for 7,500BP (coastline in red).

5.3   Primary data generation stage: Summary

The results of the primary data generation phase achieved the following objectives:

Objective 1.1: To generate topographic data and identify topographic key features from 3D seismic data.

Objective 1.2: To identify key landscape features within the 3D seismic data.

Objective 1.3: To generate a suitable soils dataset from the available mapping and 3D seismic data.

The provision of information on dominant woodland changes through time and the use of a sea level curve applied to these data supported the following objectives:

Objective 1.4: To generate mapping of tree colonisation of the study area over time

Objective 1.5: To apply sea level curve data to the data generated by the above objectives (1.1 to 1.4) to simulate inundation.

This stage of the thesis involved the production of important datasets which are required for the modelling. The successful results of this stage were an important step in achieving the aims of this thesis. The results led to the identification of major landscape features with a chronological and stratigraphical evolution. The dominant woodland maps are also of significance, providing an understanding of the evolution of the woodland in this area, together with an evaluation of the effects of sea level change on the landscape.

This chapter will continue to explore the results of the model applied to these primary datasets. It will seek to address many of the outstanding objectives of this thesis and explore the human impact of landscape change.

5.4   Model results: Introduction

The purpose of this chapter is to present the results of the modelling outlined earlier. This chapter will begin by briefly introducing the results of the qualitative model and its determination of resource yields. This, in turn, will lead to the results relation to the population capacity. The results will also be displayed in a spatial manner through the utilisation of GIS. From these base datasets, the result of the predictive model will be presented and assessed.

5.4.1 Model results: Resource yields

The detailed tables for determination of potential resource yield are large and cannot easily be presented within the body of this text. These are provided in Appendix 1. However, the seasonal resource tables for the two main environmental periods during the Mesolithic Period are presented in Table 5.1 and 5.2. The total monthly results are summarised for each environmental stage in the graphs shown in Figures 5.24 and 5.25, and these should be compared to Jochim's (1976) data (Figure 5.26).

Species	Winter	Spring	Summer	Autumn
Beaver	0.051952	0.040492	0.008013	0.008604
Boar	0.23084	0.203616	0.193887	0.173394
Comman Seal	0.024749	0.034121	0.056681	0.024833
Fish FluvioLacustrine	0.083782	0.144614	0.13352	0.131659
Fish Marine	0.102258	0.1245	0.136808	0.094415
Grey Seal	0.122538	0.103745	0.162231	0.229917
Red Deer	0.262298	0.244618	0.20621	0.240491
Roe Deer	0.026966	0.023144	0.021223	0.020472
Small Game	0.094617	0.081151	0.081429	0.076216
CHECK	1	1	1	1

Table 5.1 Table of Final Seasonal resource values (Atlantic Stage).

Species	Winter	Spring	Summer	Autumn
Beaver	0.052068	0.040544	0.008019	0.008613
Boar	0.193831	0.176795	0.173203	0.152432
Comman Seal	0.024967	0.034269	0.056917	0.024914
Fish FluvioLacustrine	0.085227	0.146063	0.134906	0.132175
Fish Marine	0.103961	0.125764	0.138152	0.095024
Grey Seal	0.124092	0.104506	0.163237	0.23043
Red Deer	0.282332	0.258967	0.215485	0.252467
Roe Deer	0.037243	0.031029	0.027777	0.027108
Small Game	0.096279	0.082064	0.082303	0.076837
CHECK	1	1	1	1

Table 5.2 Table of Seasonal resource values (Boreal Stage).
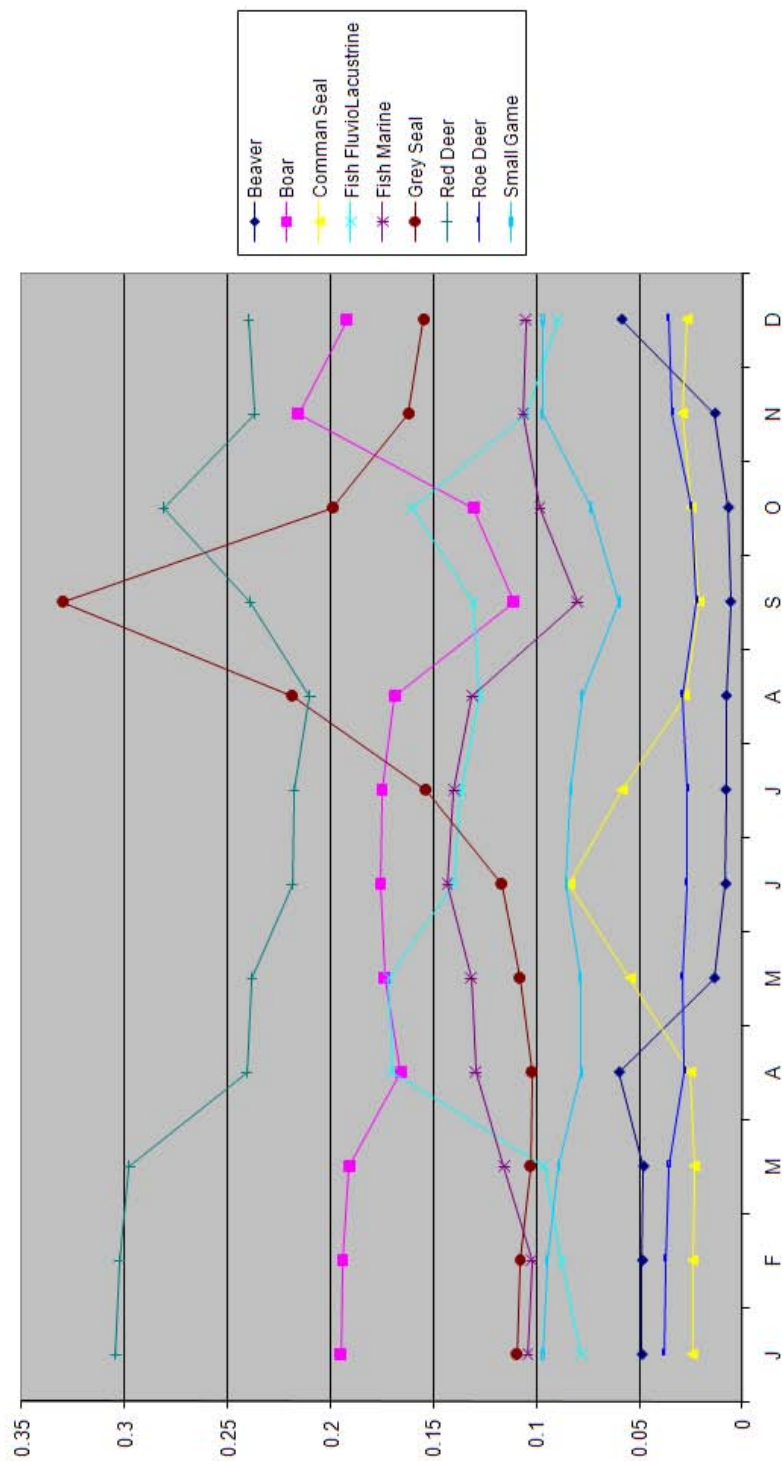
Figure 5.24 The resulting values of resource use (Boreal). Note the significant spikes related to the exploitation of seal resources. If the model is indicative, then this suggests a reliance on terrestrial resources during the winter months.
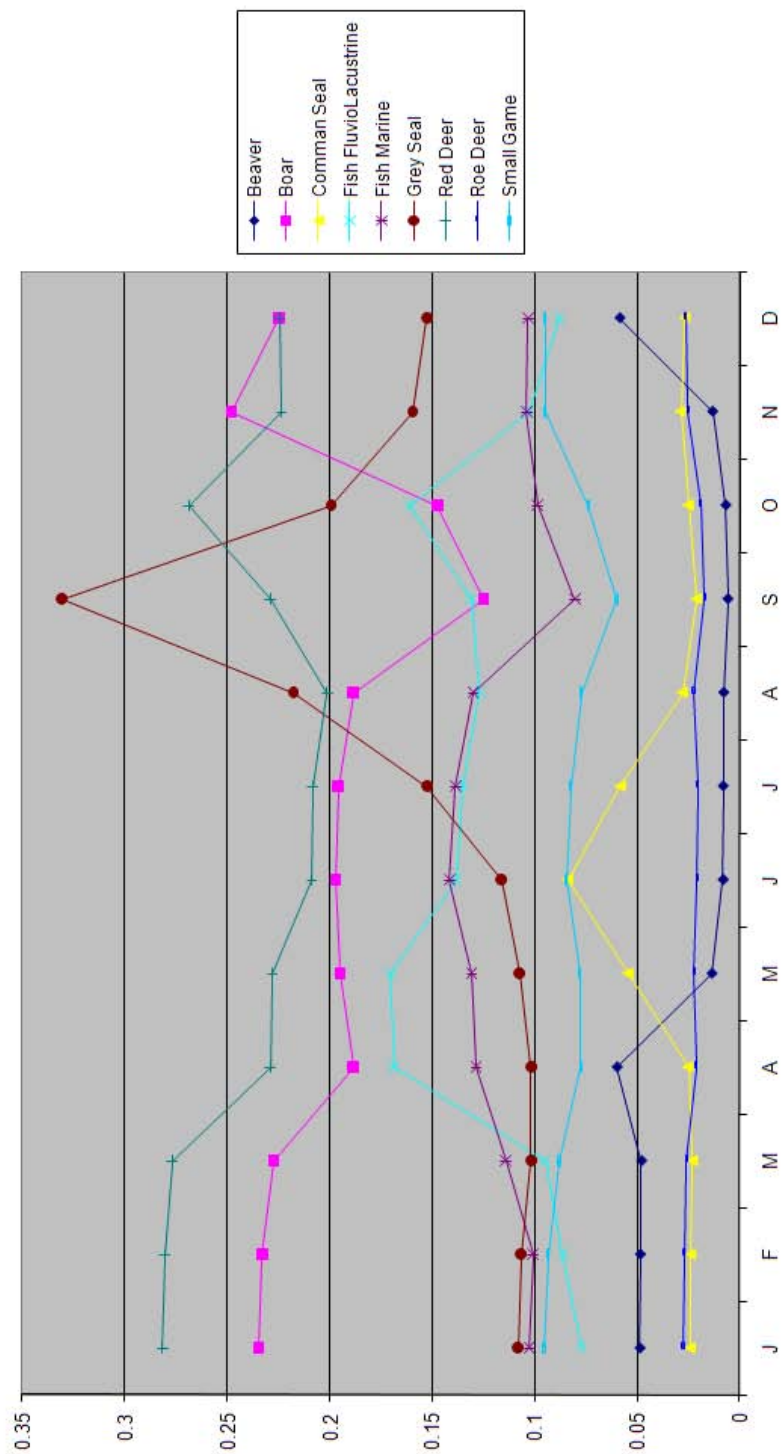
Figure 5.25 The resulting values of resource use (Atlantic). Note the significant spikes related to the exploitation of seal resources. If the model is indicative, then this suggests a reliance on terrestrial resources during the winter months.
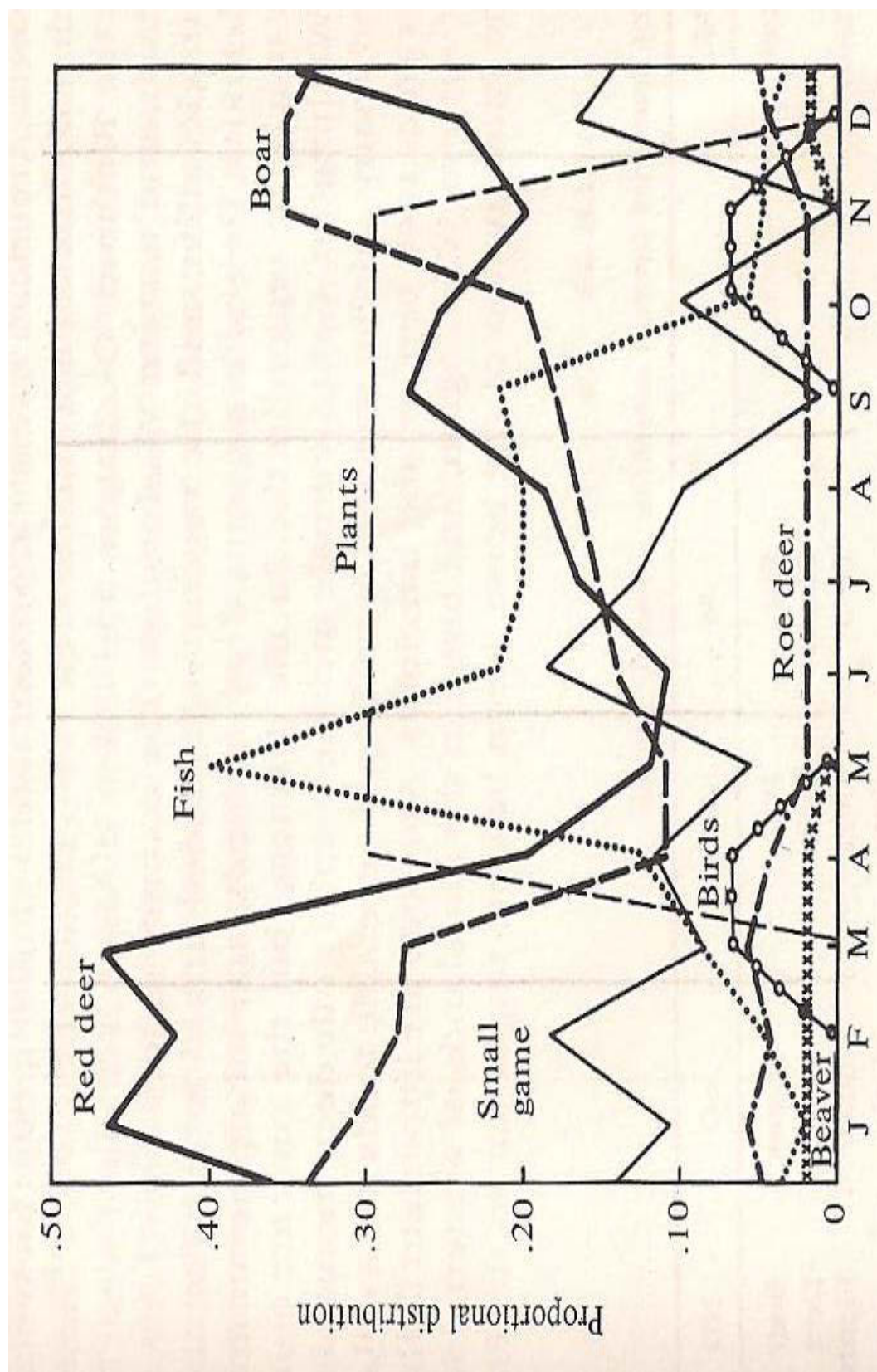
Figure 5.26 Predicted resource use schedule of the southwest German Mesolithic
(Jochim, 1976)

210

Upon examination, the resource schedule for Boreal conditions looks similar to Jochim's (compare Figure 5.24 to 5.26). For example, the graphs show that beaver is a resource that is used during the December to April period. However, the inclusion of marine resources results in an important difference. There are sharp rises for resource usage associated with grey seal during September, and also common seal in July. This is an important consideration after 9,500BP. Indeed, from these results, it is possible to make some predictions which can be checked during the later population support stages of this analysis. The prediction is that during 9,500BP, coastal resources should be heavily utilised during the autumn, whilst in the winter, although the coastlines remain important, fluvial and lacustrine areas will rise in significance.

The graph for Atlantic conditions presents changed conditions (Figure 5.25). Whilst a large number of grey seals appear to still be caught in September, higher values for wild boar and slightly lower values for red deer prevail throughout. Such a result may suggest that for the later stages of the study, we might, therefore, expect the coastal zone usage to be primarily in the autumn.

5.4.2 Model results: Landscape data

The overall trend within the landscape is for a reduction in the amount of habitable land from 4377Km^2 (10,000BP) to 484Km^2 (7,500BP) (Figure 5.27). This represents an 89% loss in land during 2,500 years. If this landscape loss is examined in terms of soil types, further insight into the effects of the marine inundation on the landscape can be gleaned. The dominant soil is "wet basic", which can be clearly seen to reduce in proportion to the area

of inundated land (Figure 5.28). However, further insights can be gained from examining

the other soil types (Figure 5.29). Alluvial soils remain stable in area until 9,000BP, when

their total area is reduced. Well drained basic soil can be seen to reduce in total area at

9,500BP, reflecting the inundation of the Outer Silver Pit. Perhaps most interesting is the

coastline area. This can be seen to increase in area until 9,000BP; This area is then reduced

between 9,000BP and 8,500BP. After 8,500BP the total area of coastline remains relatively

similar.
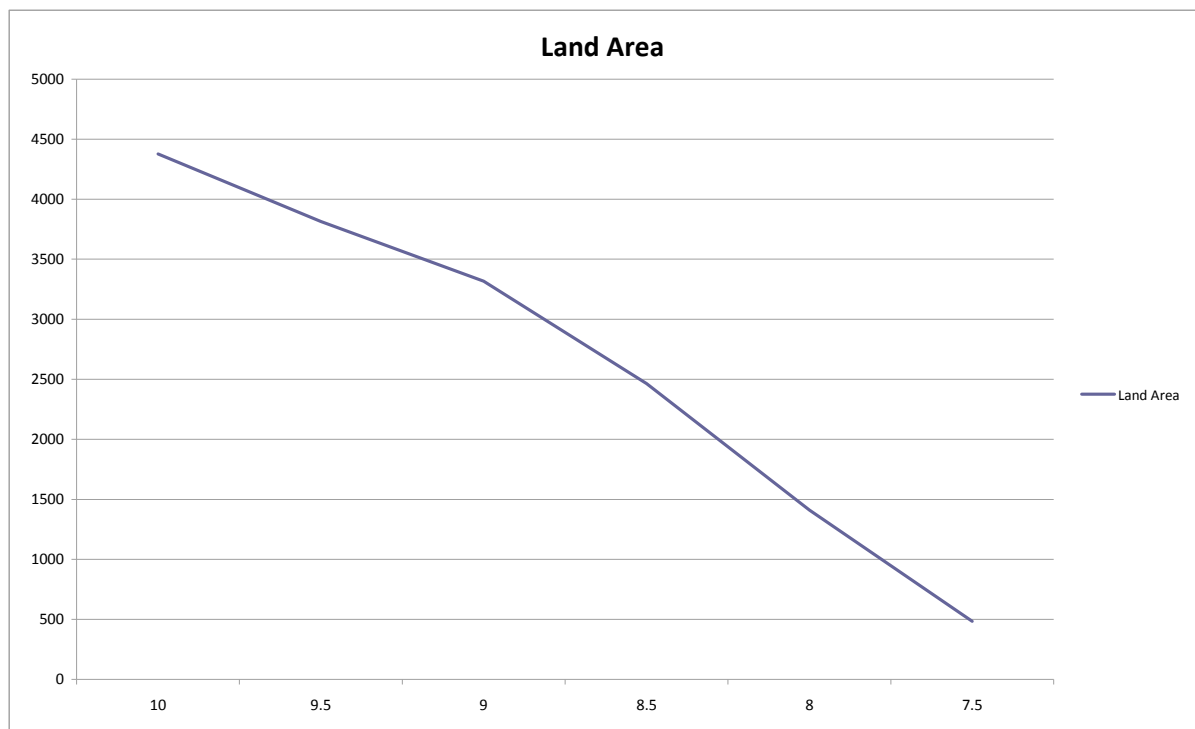
Figure 5.27 Area of habitable land (km^2) over time.

Since the landscape data shows an overall decline in habitable area (Figure 5.27), we

should, therefore, expect a similar reduction in the overall support values for the

population. Since the coastline is thought to be an important area for resources (see

section 5.4.1 of this chapter), then we should expect a minor increase in population

supported at 9,000BP to coincide with the increase in the total area of coastline. Indeed, if

we express the coastline as a percentage of the total habitable land area (Figure 5.30), then

it is apparent that there is also the potential for an increase at 8,000BP. This is made more

apparent if this is compared to the percentage of the total study area that the coastline

represents at each time interval (Figure 5.30).
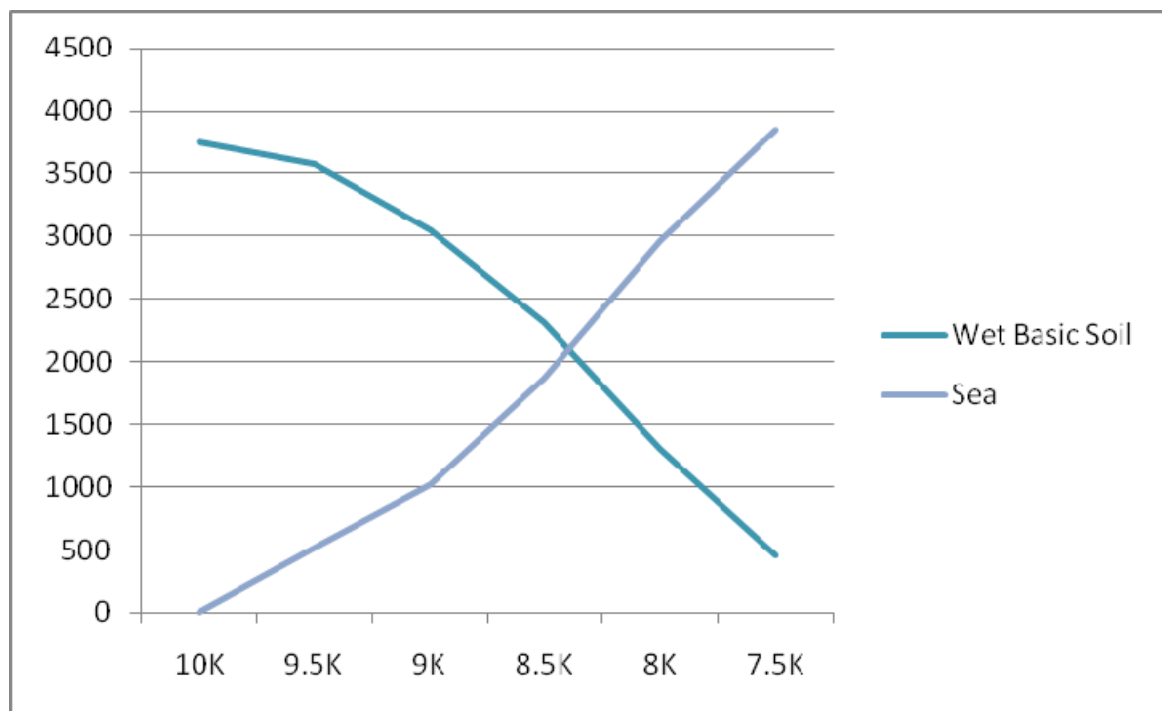
Figure 5.28 Area of study inundated (sea) and wet basic soil area over time.
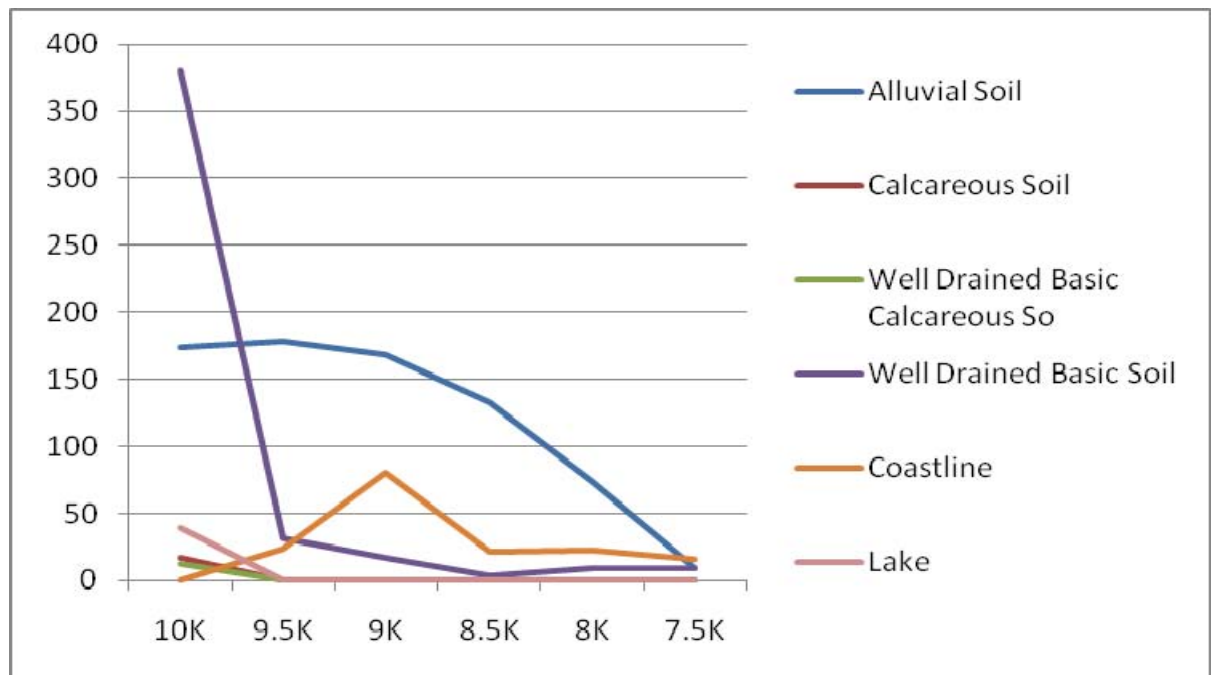
Figure 5.29 Area of lesser soil types over time.
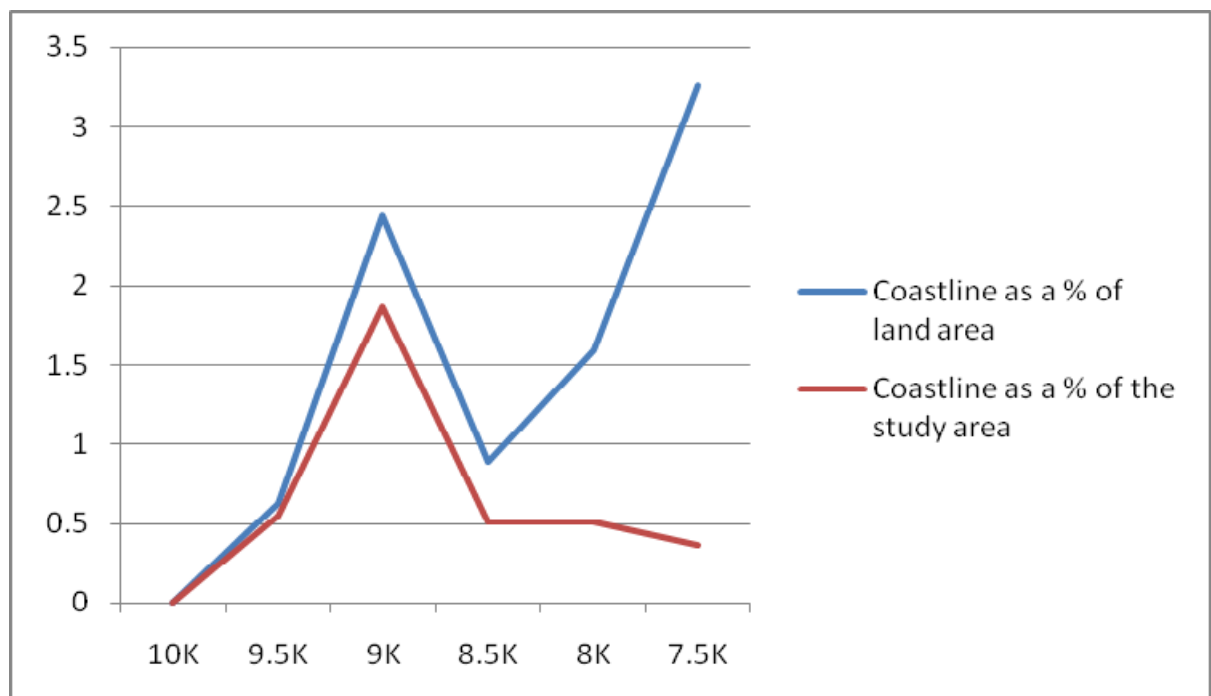
Figure 5.30 Coastline as a percentage of the total habitable land area.

5.4.3 Model results: Support values

The resource values provided were converted to potential population carrying capacity, and applied (at 500 year intervals) across the available land. It must be stressed again that the values presented represent population potential maxima values rather than a real figure. Relative change in ratios between the time intervals will therefore have the most significance.

If we examine this by species, then the results in Figure 5.31 are derived. When this is examined in relation to the results in Section 5.4.1 of this chapter, the support values may appear slightly puzzling, as grey seal appears to be able to support a larger potential population than other species. This is a product of the size of a grey seal. Therefore, even a relatively small catch could potentially support a large number of people. Thus, it could be expected that a large population could be supported on the coastline. However, the relatively small overall area of the coastline (Figure 5.30) should be held in mind. Given this situation, therefore, this result is likely to only have localised significance.

If the results are examined as a seasonal maximum supportable population over time, then further insight is provided (Figure 5.32 to 5.37 and Table 5.3). Whilst both the spring and summer maxima population values broadly reflect the overall reduction in population (Figures 5.32, 5.33), there are significant variations seen in the autumn and winter values (Figure 5.34, 5.35). The autumnal figures do not deviate greatly, but show a pronounced peak in population at 9,500BP. This rise is almost certainly due to the appearance of

marine resources in the model. The rise is driven by the availability of grey seals during

their pupping. After 9,500BP the population values return to a trend of reduction.
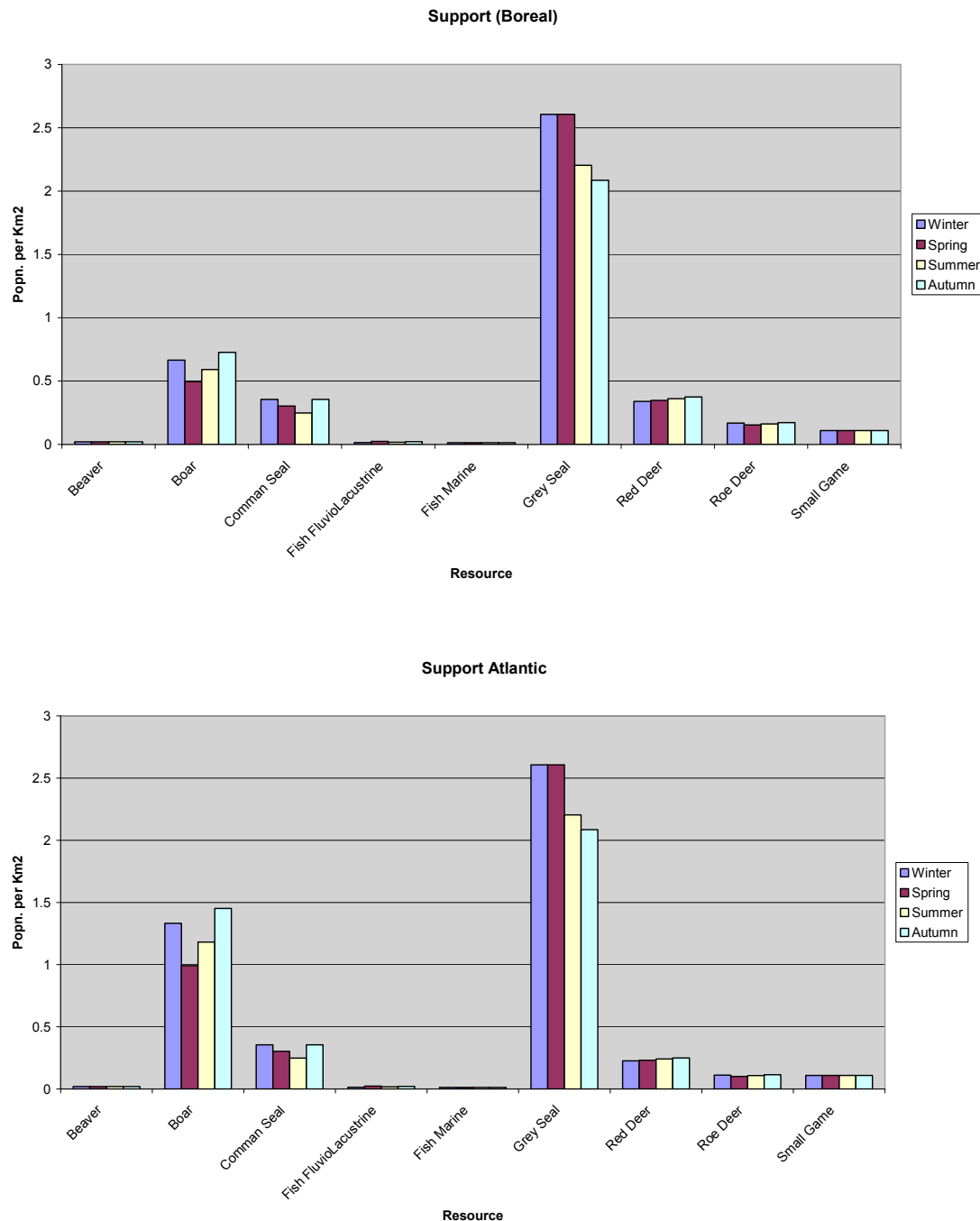
Figure 5.31 Support value graphs for the Boral (top) and Atlantic (bottom) environmental
periods (note marine species are expressed as values per km coastline).

This is significant, given the rise in coastline available (Figure 5.30). The model suggests that the resources made available by the coastline may not be sufficient to make up for the terrestrial resources lost to inundation during this time. The model demonstrates that if the parameters used are correct, then a minor rise in resources may have occurred that could have supported an increase in population at 8,000BP, this coincides with the change in environmental periods in the model.

The winter values, however, are more significant. If the values for all the seasons are examined together (Figure 5.36), then it is apparent that the winter value is likely to be the controlling factor on population potential. However at 9,000BP, there is a rise in resources that offered the potential for increased population support during the winter; this suggests for this interval the spring value may actually be the controlling factor at this time. This information suggests some important archaeological insights. If the winter results are expressed as a percentage of the summer potential population values (Table 5.4), then the effects of seasonal resource changes on the population supportable can be clearly highlighted. At 10,000BP, the supportable winter population value is only 50% of the population supportable in summer. To the population, the summer could have therefore represented a time of relative plenty, or alternatively a time of surplus that allowed resources to be stored for the following winter. If the Mesolithic population were not practicing resource storage then the maxima Mesolithic population could be expected to be controlled by the winter support values. Even if resource storage was practiced, the differences between the other seasons and winter are sufficient to suggest that the population potential is unlikely to have been greatly increased beyond that supported by

the winter resources. For 9,000BP the story is very different. The modelled resource base

indicates that the supportable winter population value is some 81% of the summer value,

and is greater than the spring value. In this case the lower resources in spring may be the

controlling factor. However, given the possibilities presented by food storage, and the

proximity of the winter and spring values, it is likely that the slightly higher winter value

may still be the controlling factor. Therefore, the model and the resource data suggest

there is the potential for a larger, possibly more stable population during 9,000BP.

It is possible to interrogate the modelled data further (Table 5.5). If the values provided by

the model are expressed as a percentage of the maximum supportable population for

winter, then clear changes in the potential population can be observed and quantified. The

potential maximum supportable population can be seen to rise some 25% of the maxima

value between 10,000BP and 9,000BP. At 9,000BP the maximum potential population

support for the entire model is reached. However, after this, at 8,500BP the model

suggests that there is a sharp fall in resources, and hence potential population, and this

support value falls to only 37% of the maximum value. This fall in the modelled resources

between 9,000BP and 8,500BP represents a reduction of 63% in the potential supportable

population. At 8,000BP the resources available to support potential population rises again

to 47% of the maximum value. This rise in resources is due to the onset of Atlantic

conditions. However, by 7,500BP the resources to support the potential population have

fallen again to some 16% of the maximum value. This loss in resources and hence

population potential, results in a population potential that is only 30% of the maximum

potential population value reached in the model.

It is clear from the potential population values that the model predicts a large fall in the maximum supportable population at around 8,500BP and a smaller one at 7,500BP. However, this is not reflected in the potential population density figures provided by the model. If we examine the potential population density results for the habitable land area (Table 5.6), then it is apparent that the model is predicting an increasing potential for higher population densities (Figure 5.37). Logically this would fit with a population being required to live upon an increasingly small area. The reduction in the rate of increase towards the end of the inundation would indicate that an optimum density, in terms of resources, is being approached. However, there is a major deviation from this, at 8,500BP, which requires explanation (see Table 5.6 and Figure 5.37). This sees a fall in potential population density from 15.7 at 9,000BP to 7.9 at 8,500BP. It is important to note that this value is even less than the potential density value for 10,000BP (8.9). Upon examination, it is apparent that this loss in potential density within the model coincides with a major loss in resources to support a population (see Table 5.5), a loss in coastline (Figure 5.30), and an increasing rate of inundation (Figure 5.28). This loss in potential population density is, therefore, understandable, as the model suggests that there are fewer resources to support high population densities, because of the loss of coastline. The increased rate of inundation remains a potentially problematic point to this solution. However, this should be considered in light of the drop in coastal area within the model. At 9,000BP the coastal area represented some 2% of the total study area (Figure 5.30); however, by 8,500BP this had dropped to only 0.5%. Since the coastline is capable of providing resources that could support high population densities, the drop in this area represents an important reduction in capacity. Therefore, this combination of a reduction in overall landscape and coastline,

and thus resources, represents a potential impact upon the Mesolithic populations within the region. This loss in potential population, combined with a reduction in potential population density over a relatively short period of time (500 years), suggests that an opportunity for population displacement exists, if the maximum population densities predicted by the model were achieved by Mesolithic populations in the North Sea. However, if populations existed at considerably lower densities than predicted in the model, it is possible that displacement may not have occurred.

If it occurred, then such a major change with respect to population supportable and its density potentially has cultural implications. At 10,000BP, with relatively low population densities predicted across the whole study area, a nomadic existence is likely. However, from 9,500BP to 9,000BP, with the presence of marine resources, the model suggests that large population numbers could have been achievable. The densities within the interior of the landscape remain unchanged from 10,000BP (Table 5.3) until 9,000BP, when the reduction in landscape becomes sufficient to cause the population density to fluctuate. This suggests a nomadic lifestyle remained within the interior, and may even have been supported in later years by the resource reduction predicted by the model. Conversely, the increase of high resource density coastline (Table 5.3) allows for greater population potential and densities than in the terrestrial zones. As such, the conditions in the model would appear to support sedentary groups in the coastal area. The modelled results suggest therefore that conditions existed that may have allowed significant cultural differences to occur between terrestrial and coastal populations. The values of Table 5.3 suggest that the terrestrial zone would have had the potential to be populated by high

numbers of small groups that were relatively well dispersed within the landscape. For the

coastal zone a different picture emerges, with the results of Table 5.3 suggesting the

potential for small numbers of large groups, occupying a relatively small area in terms of

the landscape.

This information is perhaps most useful when applied within the GIS. This shows the effects

of these changes (represented here as maxima values) over time and space. These can be

found in summary form in Figures 5.38 to 5.44, and in higher resolution in Appendix 2.

These maps illustrate the results for both total maxima supportable population for winter

(Figure 5.38), and potential population density (Figures 5.39 to 5.44). Figures for total

maxima supportable population are only provided for winter, as the total population maps

present a broadly similar picture for all seasons. The figures for total maxima supportable

population for all seasons are therefore provided in Appendix 2. This GIS representation

highlights some interesting changes within the modelled population support in relation to

the changes in the landscape. For example, on examination of the total supportable

population, it can be seen that the highest numbers are situated on the wet basic soils

(shown in blue on Figure 5.38). This trend continues throughout the model. This is

primarily caused by the large size of these zones and their resources relative to the other

areas. Significantly, one of these areas and its resources are lost to marine inundation at

8,500BP, the inundation represents the main loss in population potential within the model

at this time. The GIS also illustrates that, due to the small area of coastline, the coastline

has the potential to support relatively small total numbers in comparison to the wet basic soil area. Yet, the coastline has the potential to support a population which is similar in size to that predicted for alluvial soils. This occurs in spite of the fact that alluvial soils cover a significantly larger area in relation to the coastal zone.

If the potential population density is examined within the GIS, similar insights can be gleaned. Winter at 10,000BP produces some unexpected results with the influence of overall soil type on plant species playing a major factor in the location of potential for aggregation. This produces a regional high within the model in the north of the study area. At 9,500BP the marine incursion has begun in the Outer Silver Pit. The presence of a marine environment is represented by high potential population densities within the coastal zone. However, there are seasonal increases in potential population density with respect to rivers during autumn and winter. This is probably a reflection of seasonal fish runs and beaver availability within the model. The marine inundation continues through to 9,000BP. However, only minor changes in the overall potential population density are observable in the data. Locally, the increase in coastline due to inundation leads to a spread of high potential population density zones within the model. The GIS at 8,500BP illustrates the effects of the increasing marine inundation within the modelled landscape. Approximately 45% of the study area is now submerged. Rivers now remain areas of increased potential population throughout the seasons, and this change is thought to be a reaction to the relative loss of terrestrial resources within the model.

By 8,000BP nearly two thirds of the study area is inundated. The change to more Atlantic environmental conditions is seen to increase the supportable densities across the region. Because of this change and the increase in resources within the model, the potential population density at the rivers becomes less during the summer months. However, due to the increase in the percentage of coastline relative to habitable land (Figure 5.30), the effect of the coastal areas is now more apparent within the modelled data. At 7,500BP most of the landscape is inundated, and only a very small area of habitable land remains. This is surrounded by a coastline with the potential for high population densities. It is apparent from the map that the marine inundation would have shutdown almost all of the fluvial systems in the area. It is, therefore, likely that fresh water may have been a scarce resource, and this appears to be reflected in the predicted alluvial population densities.
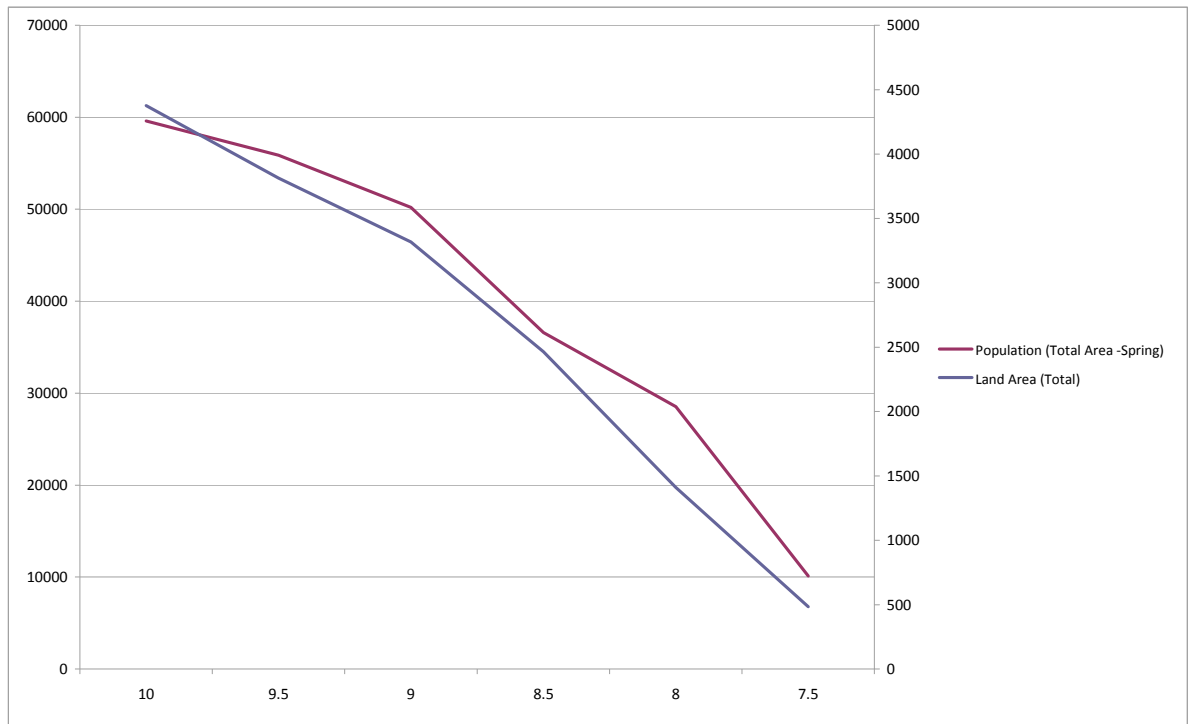
Figure 5.32 Total maxima population over time (Spring). The overall habitable land area is also provided for comparison.
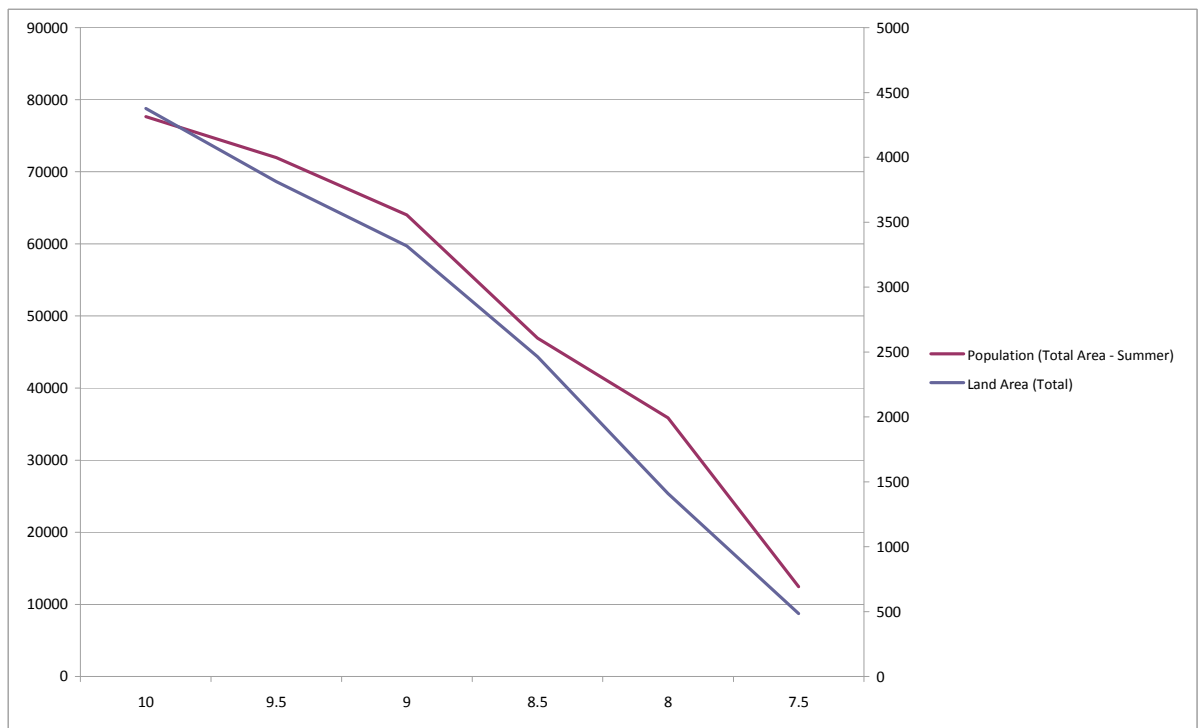
Figure 5.33 Total maxima population over time (Summer). The overall habitable land area is also provided for comparison.
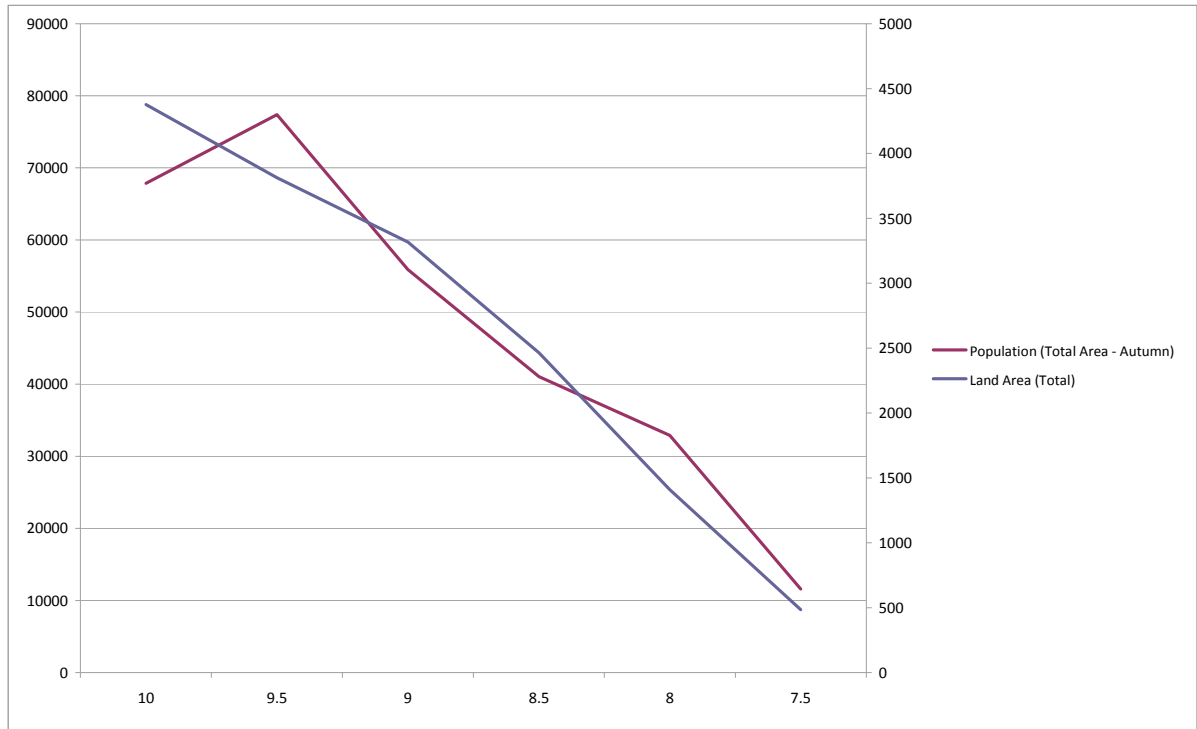
Figure 5.34 Total maxima population over time (Autumn). The overall habitable land area is also provided for comparison.
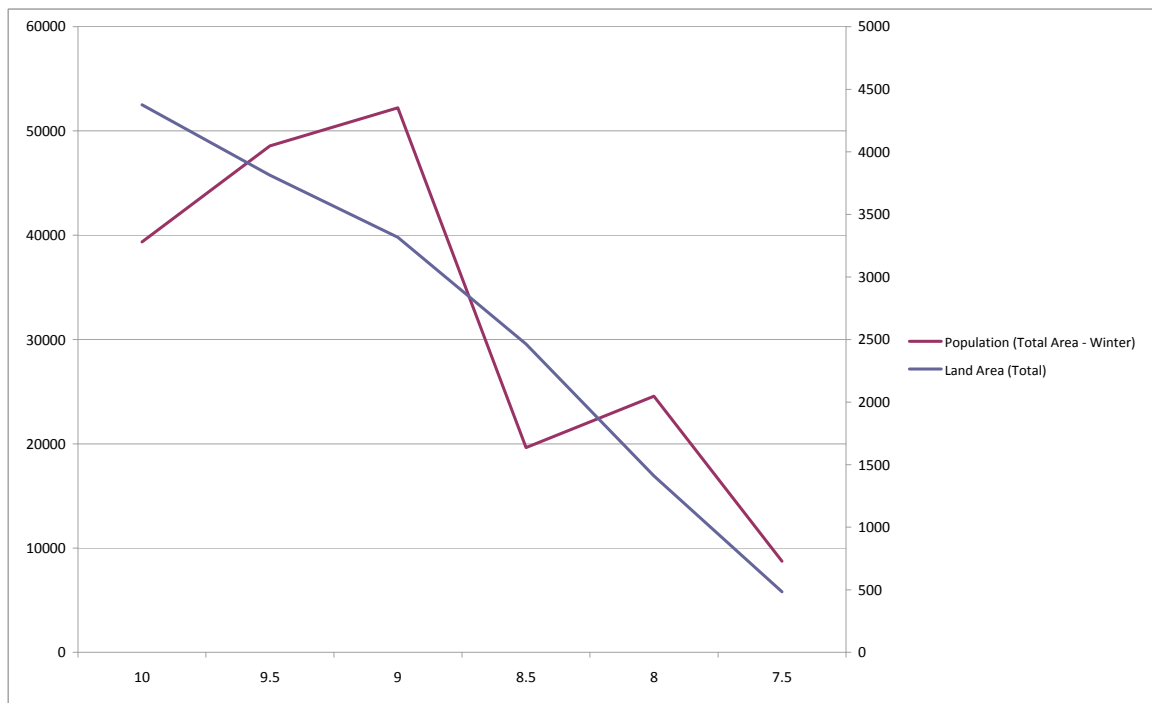
Figure 5.35 Total maxima population over time (Winter). The overall habitable land area is also provided for comparison.
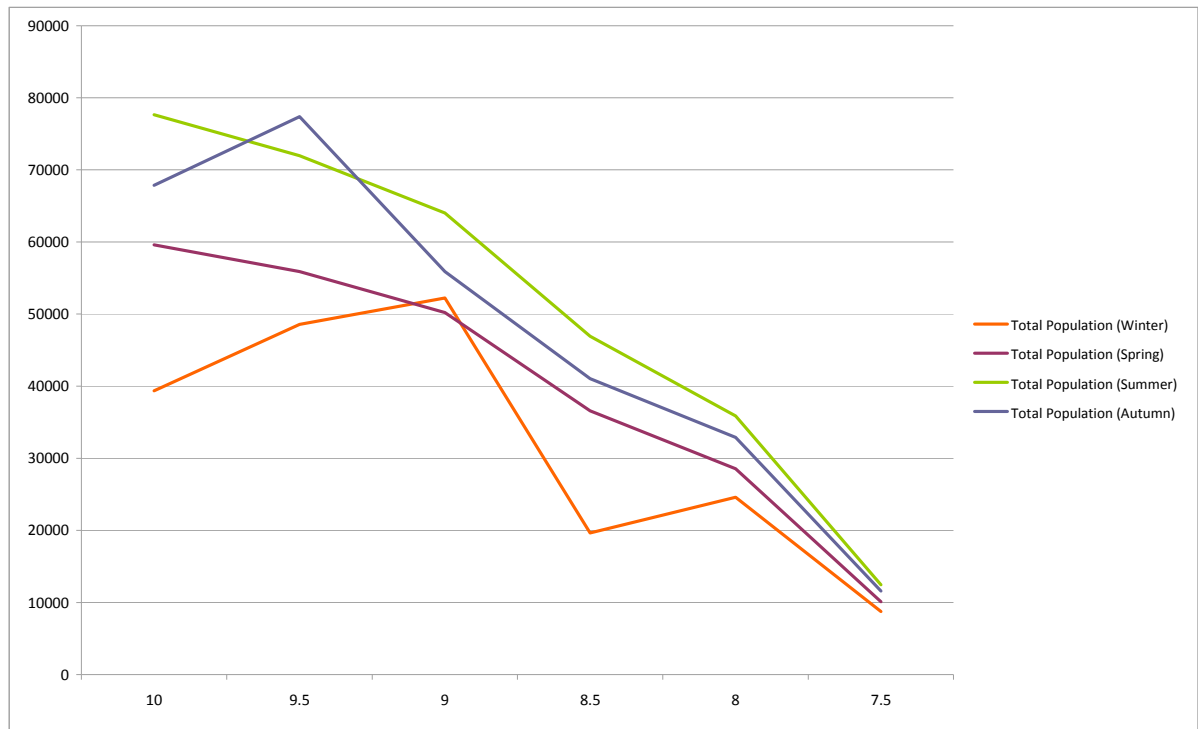
Figure 5.36 Total maxima population over time (All seasons). From this it is clear that with the exception of 9,000BP the winter total population value is likely to be the controlling factor.
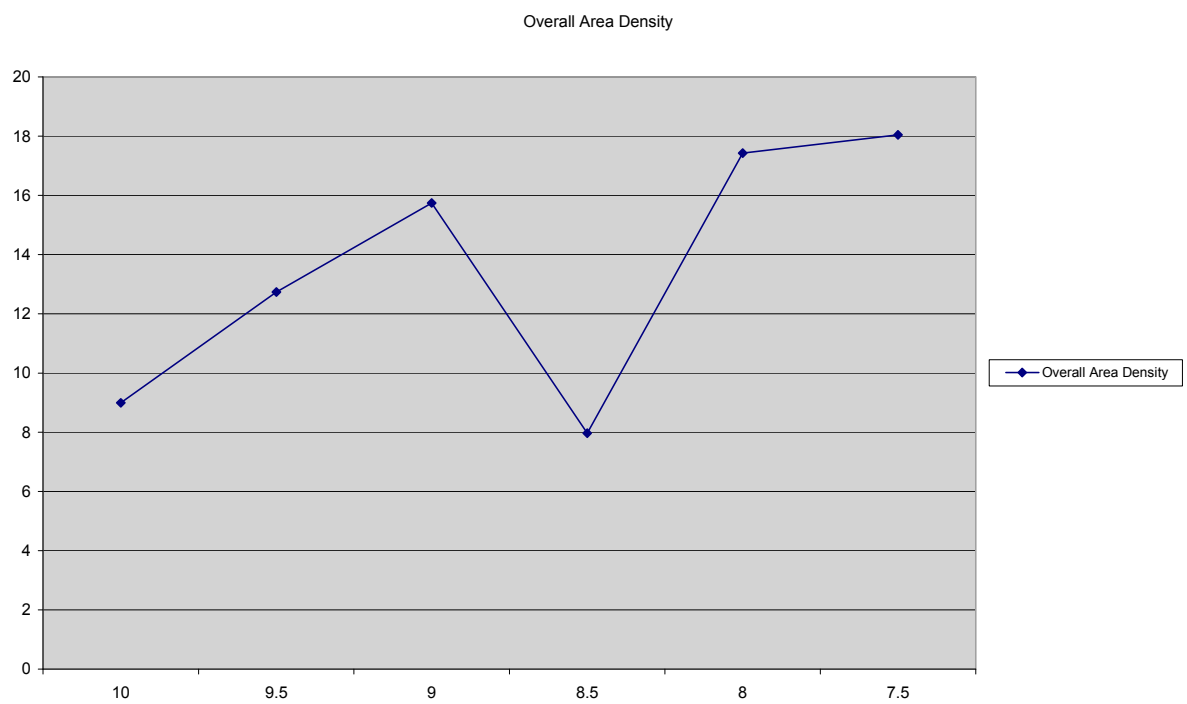
Figure 5.37 Population density changes for the area of habitable land over time.

Land Area	10K_BP	9.5K_BP	9K_BP	8.5K_BP	8K_BP	7.5K_BP
Alluvial Soil	174	179	169	133	74	9
Calcareous Soil	17	0.63	0	0	0	0
Well Drained Basic Calcareous Soil	12.51	0	0	0	0	0
Well Drained Basic Soil	380	31	17	3.4	9.12	9
Wet Basic Soil	3754.5	3579	3050	2306	1304	450
Coastline	0	24	81	22	22.4	15.78
Sea	0	524	1020	1873	2961	3854
Lake	39	0	0	0	0	0
	4377	4338	4337	4337	4371	4338
Land Area (Km2)	4377	3814	3317	2464	1410	484
Population	10K_BP	9.5K_BP	9K_BP	8.5K_BP	8K_BP	7.5K_BP
Alluvial Soil	2266	2332	2183	1669	1354	159
Calcareous Soil	110	4	0	0	0	0
Well Drained Basic Calcareous Soil	82	0	0	0	0	0
Well Drained Basic Soil	2496	203	63	4.5	43	43
Wet Basic Soil	34405	44628	45242	16693	21751	7515
Coastline	0	1404	4730	1264	1423	1017
Sea	0	0	0	0	0	0
Lake	0	0	0	0	0	0
Total Population	39359	48571.1	52218	19630.5	24571	8734
Total Population (Less Coastal)	39359	47167	47488	18367	23148	7717
Population Density	10K_BP	9.5K_BP	9K_BP	8.5K_BP	8K_BP	7.5K_BP
Alluvial Soil	13.0229	13.0279	12.9171	12.5488	18.2973	17.6666
Calcareous Soil	6.47058	6.50793	0	0	0	0
Well Drained Basic Calcareous Soil	6.55475	0	0	0	0	0
Well Drained Basic Soil	6.57288	6.54838	3.70588	1.32352	4.71491	4.77777
Wet Basic Soil	9.16367	12.4694	14.8334	7.23894	16.6802	16.7000
Coastline	0	58.5	58.3950	57.4545	63.5267	64.4486
Sea	0	0	0	0	0	0
Lake	0	0	0	0	0	0

Table 5.3 Overall result summary by soil type.

Ka BP	Land Area	Population Winter	Population Summer	*Winter as a percentage of Summer*
10	4377	39359	77662	*50.67986918*
9.5	3814	48571	71975	*67.48315387*
9	3317	52218	64012	*81.57532963*
8.5	2464	19630	46919	*41.83806134*
8	1410	24571	35870	*68.50013939*
7.5	484	8734	12458	*70.10756141*

Table 5.4 Overall winter population as a percentage of the summer population

Density						
Ka BP	Land Area	Controling Value	Density	Change in Population	% of Maximum Population	
10	4377	39359	8.99		75.37	Rising Population
9.5	3814	48571	12.73	9212	93.01	Rising Population
9	3317	52218	15.74	3647	100	Maximum Population
8.5	2464	19630	7.96	-32588	37.59	Falling Population
8	1410	24571	17.42	4941	47.05	Rising Population
7.5	484	8734	18.04	-15837	16.72	Falling Population

Table 5.5 Percentage change in population relative to the maximum winter population.

Ka BP	Density	Change in Density	% Density Change	
10	8.992232122	N/A	N/A	N/A
9.5	12.73492396	3.742691842	37.42691842	Gain in density
9	15.74253844	3.007614474	31.65909973	Gain in density
8.5	7.966720779	-7.775817659	-86.39797399	Loss of density
8	17.42624113	9.459520356	111.2884748	Gain in density
7.5	18.04545455	0.619213411	7.740167634	Gain in density

Table 5.6 Percentage change in population density for winter.
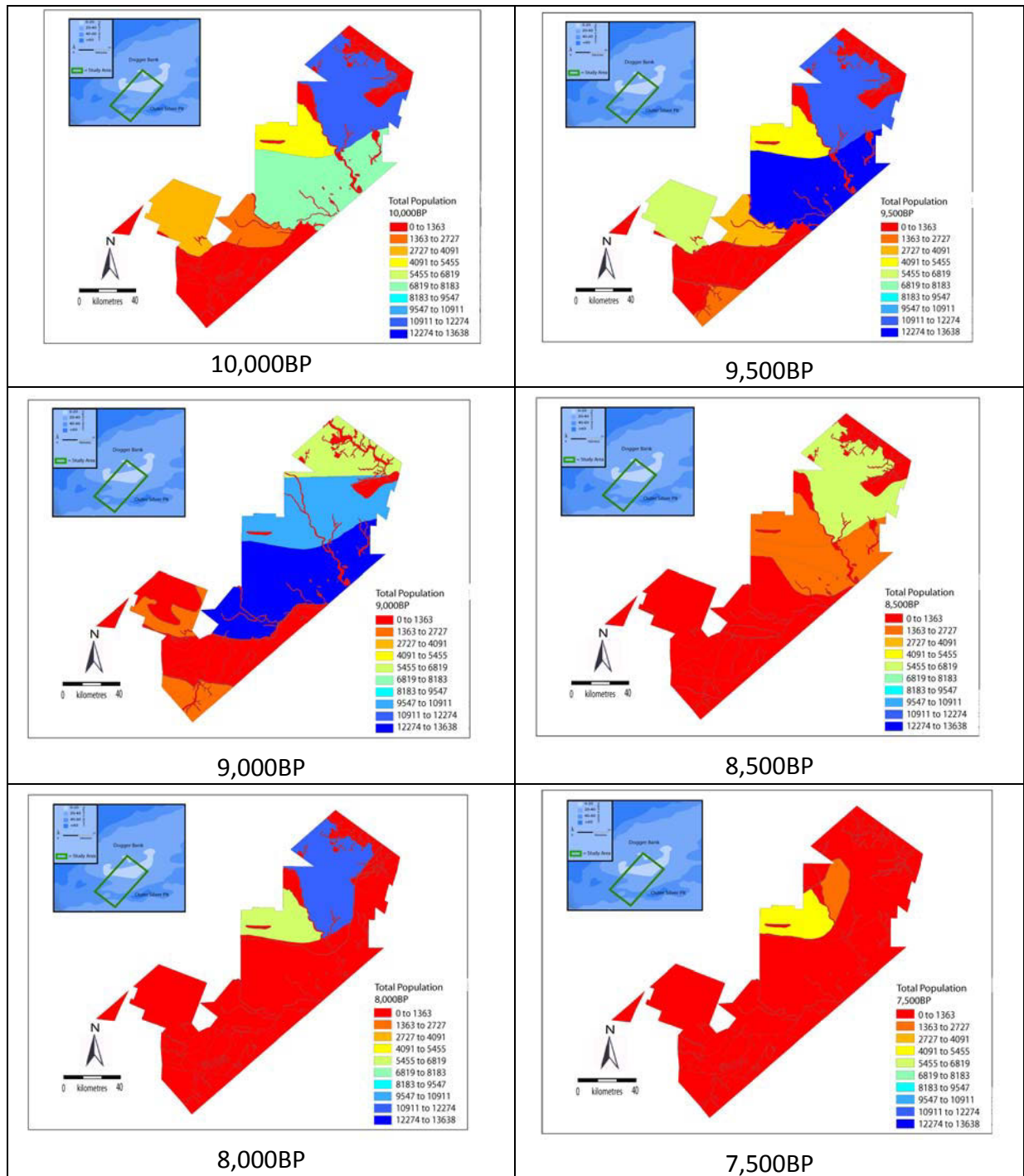
Figure 5.38 Maxima supportable population maps for the time range 10,000BP to 7,500BP (detailed maps for all seasons can be found in Appendix 2).

Winter – 10,000BP

Spring – 10,000BP

Summer – 10,000BP

Autumn – 10,000BP
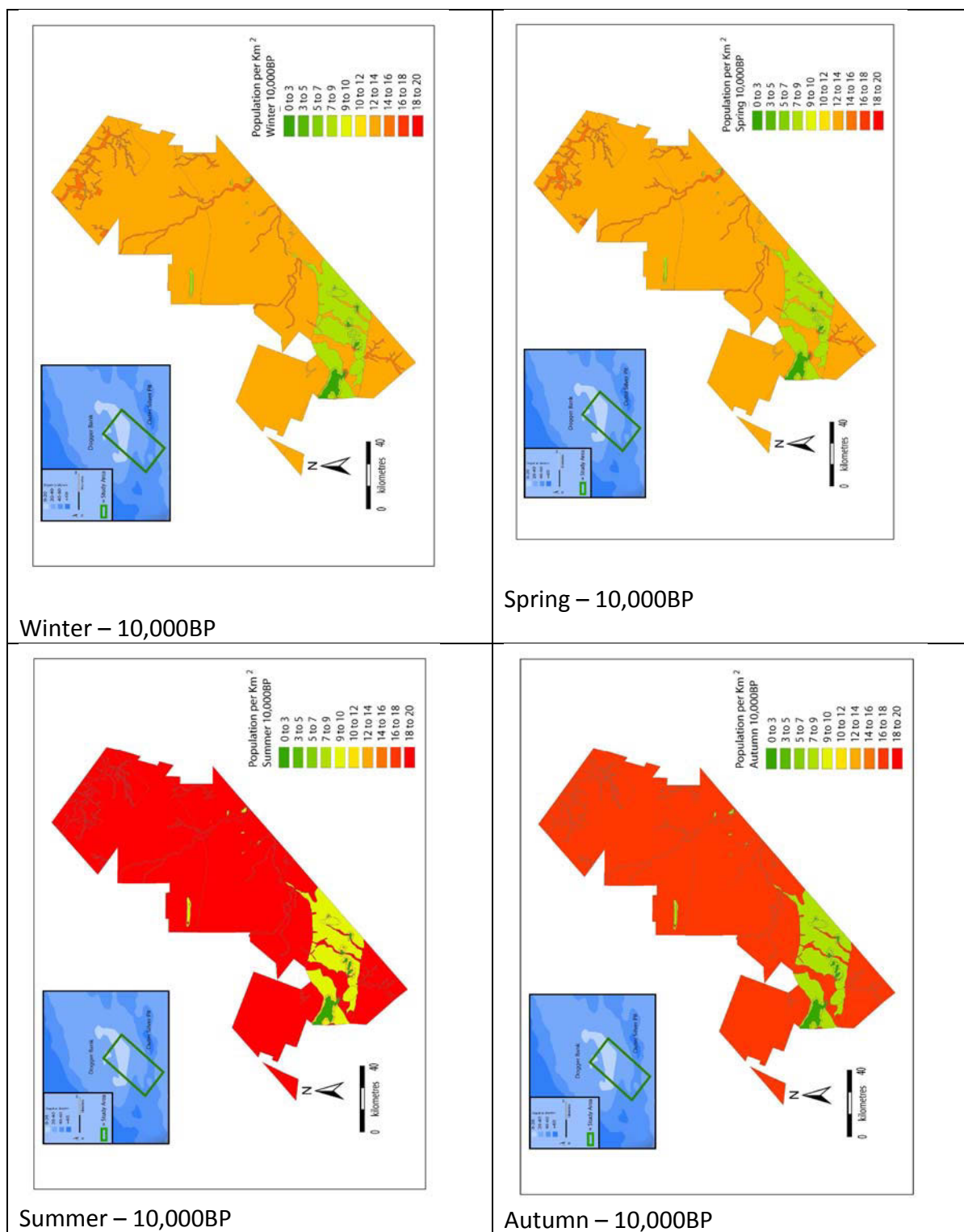
Figure 5.39   Summary of maps for maxima potential population density values for 10,000BP (detailed maps can be found in Appendix 2). Note: A smaller colour bar range is used in these maps to allow the display of area differences at low population densities.

Winter – 9,500BP

Spring – 9,500BP

Summer – 9,500BP

Autumn – 9,500BP
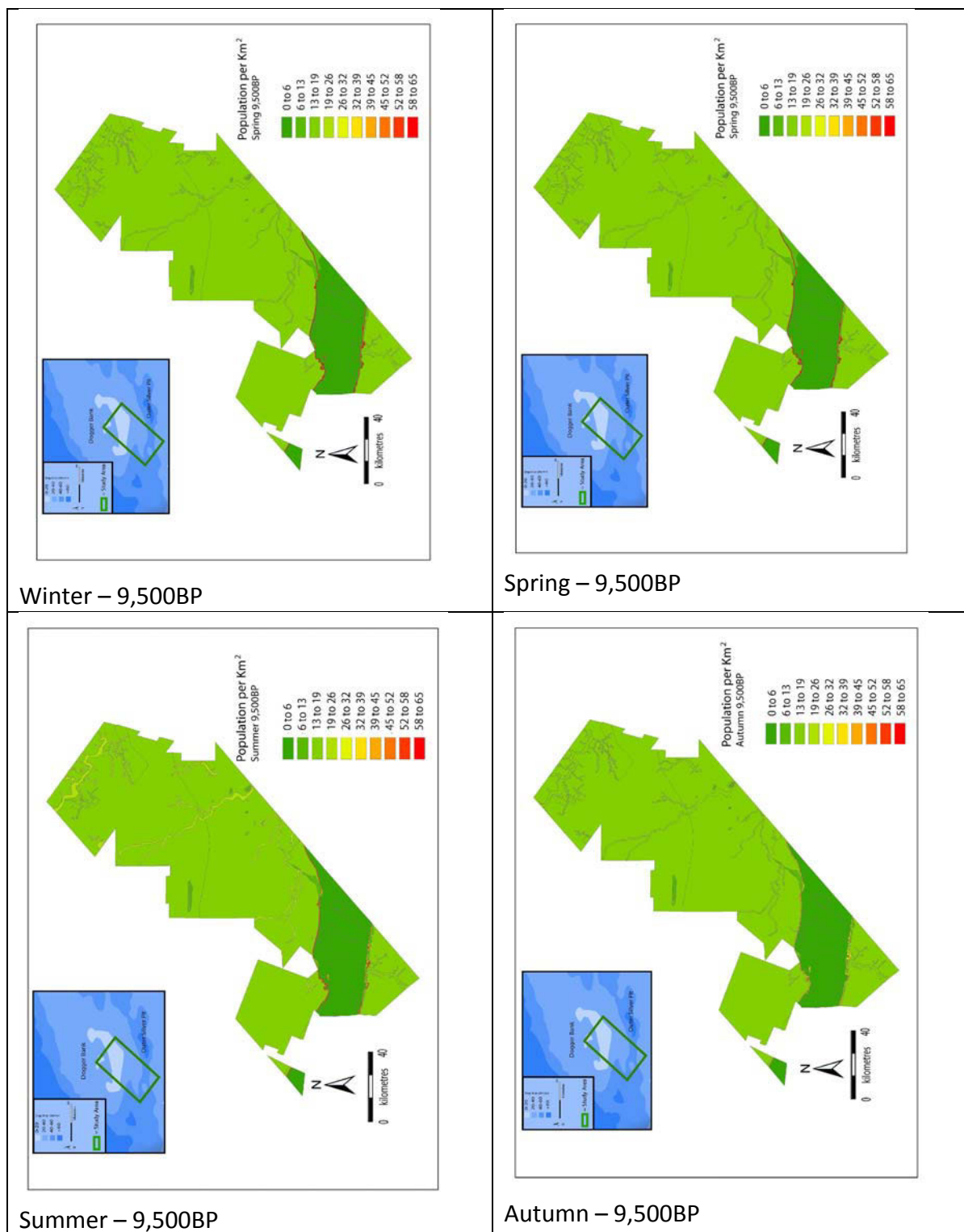
Figure 5.40   Summary of maps for maxima potential population density values for 9,500BP (detailed maps can be found in Appendix 2).

Winter – 9,000BP

Spring – 9,000BP

Summer – 9,000BP

Autumn – 9,000BP
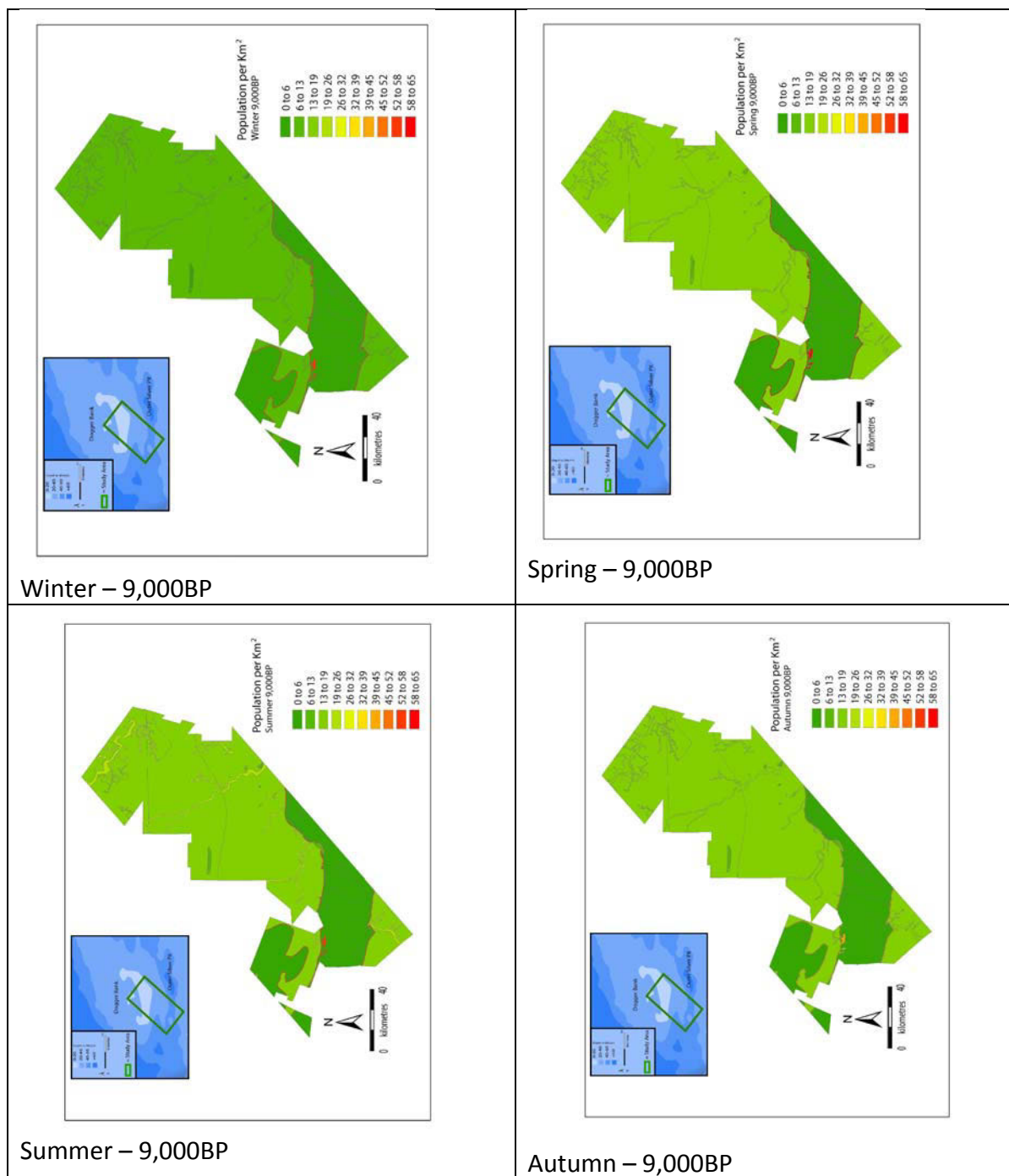
Figure 5.41 Summary of maps for maxima potential population density values for 9,000BP (detailed maps can be found in Appendix 2).

Winter – 8,500BP

Summer – 8,500BP

Autumn – 8,500BP
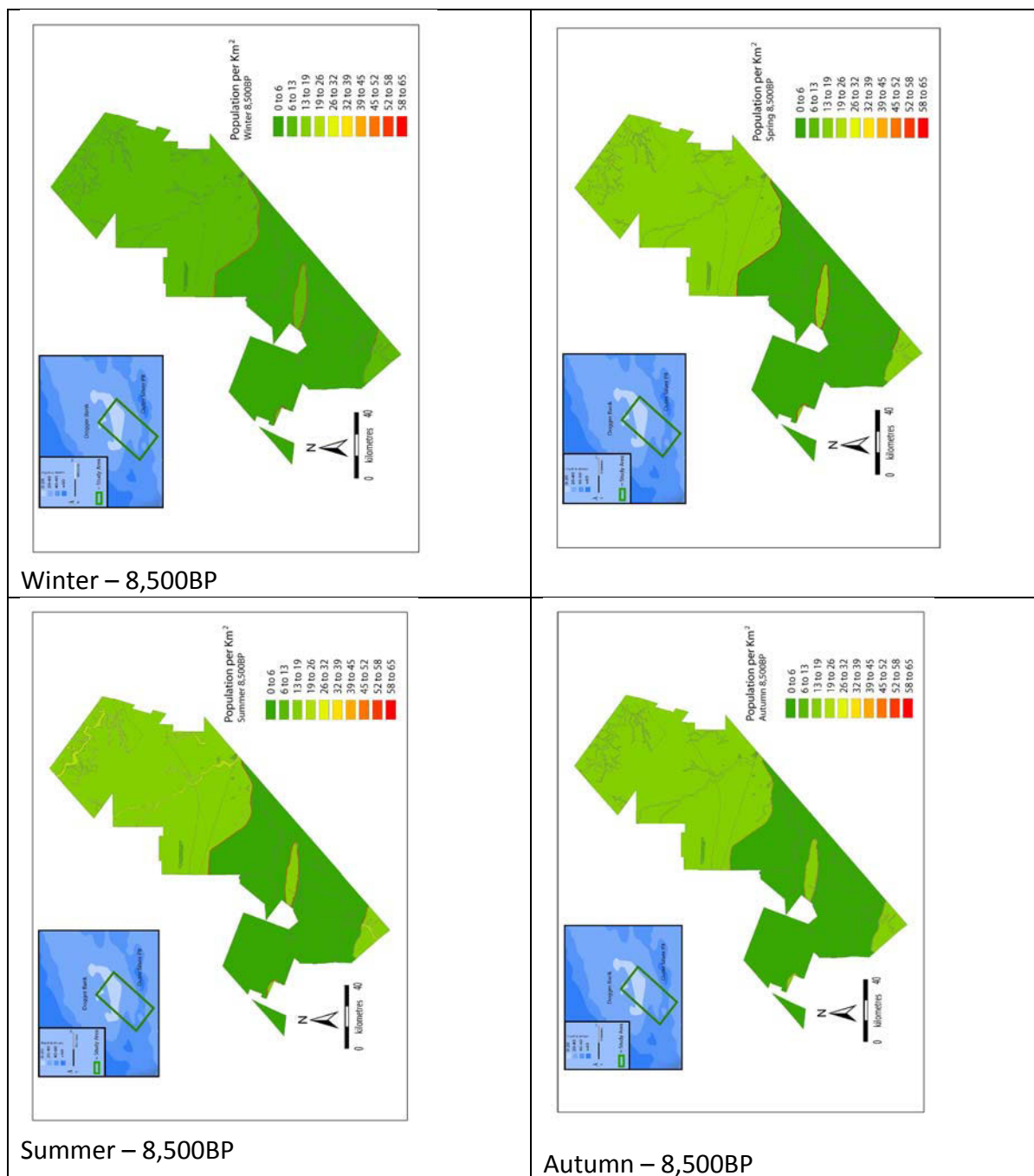
Figure 5.42   Summary of maps for maxima potential population density values for 8,500BP (detailed maps can be found in Appendix 2).

Winter – 8,000BP

Spring – 8,000BP

Summer – 8,000BP

Autumn – 8,000BP
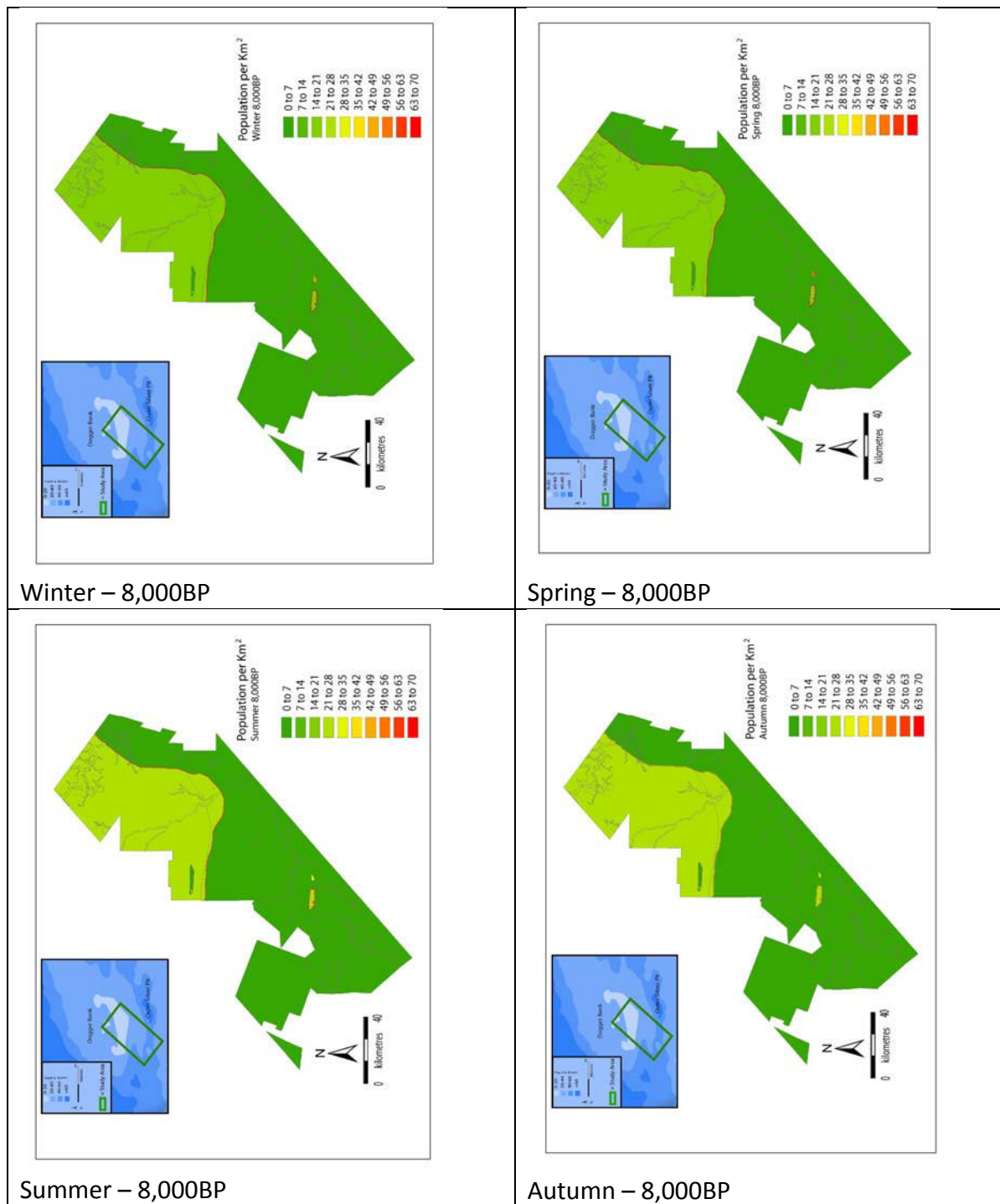
Figure 5.43 Summary of maps for maxima potential population density values for 8,000BP (detailed maps can be found in Appendix 2).

Winter – 7,500BP

Spring – 7,500BP

Summer – 7,500BP

Autumn – 7,500BP
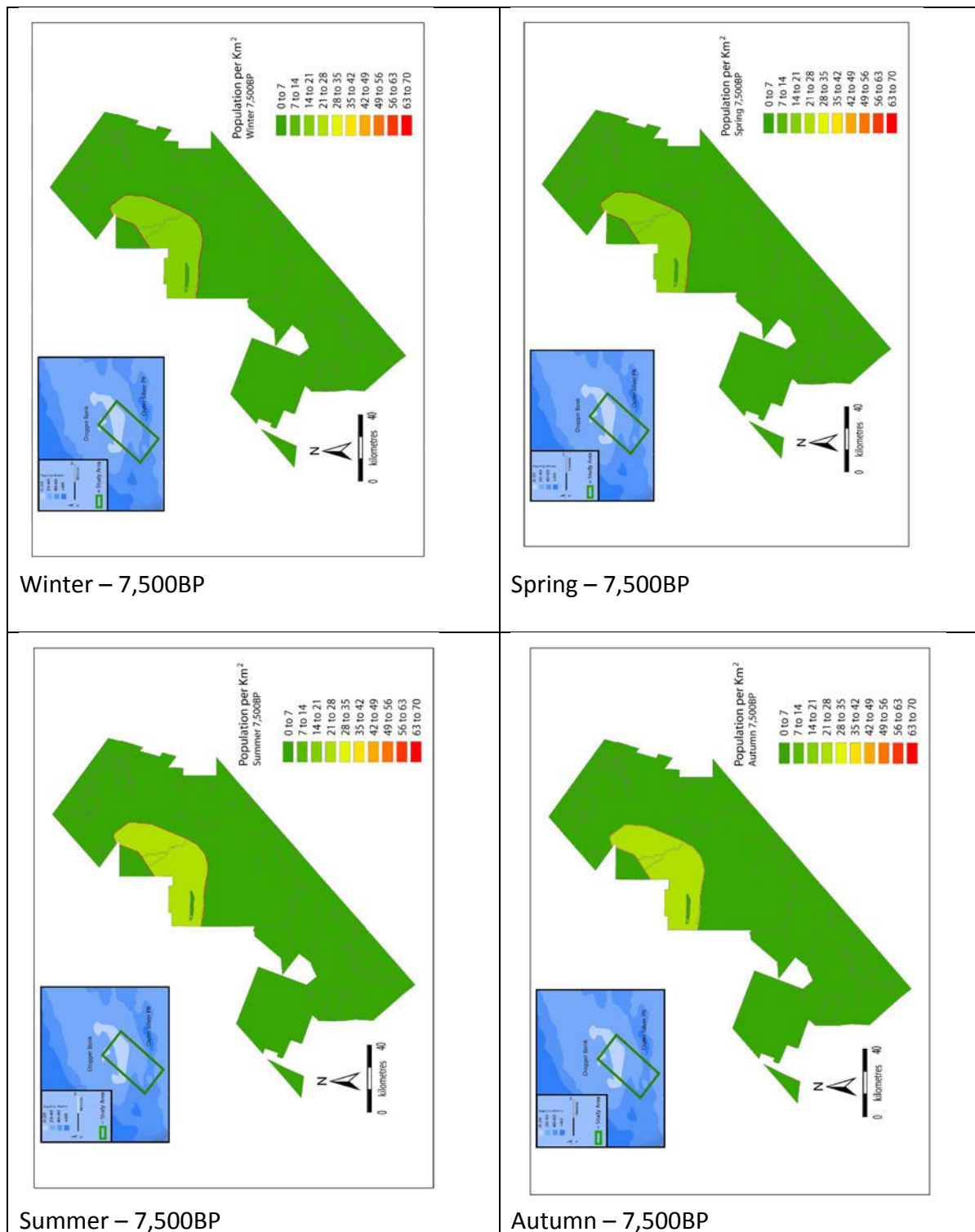
Figure 5.44 Summary of maps for maxima potential population density values for 7,500BP (detailed maps can be found in Appendix 2).

5.4.4 Model results: Support value summary

The overall trend within the model is of a reduction in the resource base through time as the landscape is slowly inundated, this may have had an impact on the contemporary human population. As submergence progresses, so the population is forced into a smaller habitable landscape, thus the population density increases. Yet, there are deviations from these trends within the data. The maximum population figures clearly show that the loss in landscape did not necessarily result in a loss of population since the resource base was sustained. The buffering effect caused by the presence of marine resources can be seen to stave off this loss for a considerable period of time. It is only when the landscape fragments, and the length of coastline is seriously reduced, that the relationship between landscape loss and population potential loss is established.

The maximum population potential figures also show that much larger numbers of people could have been present in the terrestrial zones of the landscape, in comparison to the coastal zone. If this prediction is taken in isolation, then it suggests that the terrestrial areas could have been more attractive areas for habitation. Yet, when we consider the potential population density figures, the picture becomes more complex. From the models population density figures, the coastline appears to be the optimal area for habitation due to its ability to support higher population densities. How are we to interpret, therefore, these two results from the model? If we consider the figures in parallel, then the following insight is gained from the model. The data suggests that terrestrial areas are capable of supporting large numbers of people, primarily due to their large area. However, this is at the expense of population aggregation (density) due the dispersal of the resources across a

large area. Thus, to utilise these modelled resources, it is likely that the large potential

population would have to move around this broad landscape in small groups. This would

support a hypothesis that these "interior" people could be more nomadic in nature, and

may be less likely to produce structures such as houses (e.g. Howick). Conversely, the

coastline, whilst being smaller in physical area and thus supporting a smaller modelled

population than the terrestrial zone, could support higher group sizes (and hence

population densities) within the given area. Such an aggregation of people predicted by the

model may allow more complex social interaction and behaviour to occur. Further, the

density of the resources in the models coastal zone would require smaller movements

within the landscape. Thus, the model suggests that there is an opportunity for sedentism

in the landscape. As such the model therefore suggests that, for this landscape, if

coastlines are present, there is the possibility of two patterns of grouping. One of these is

likely to have a high potential group size, be coastally based, and could be fairly sedentary

in nature. The other is more likely to be based in land, range over large areas for resources,

and potentially have a smaller group size. Such a result from the model is not inconsistent

with the archaeological record, and Nordqvist (2000), observes a similar situation from

Swedish the coastal sites.

At 8,500BP, significant reductions in population potential and potential population density

within the model occur, and there is also a major loss of coastline. This population

potential reduction is caused by acceleration in the marine inundation. As such, 8,500BP

represents a tipping point within the model where the new resources generated by

inundation are outstripped by the pace of landscape loss. If the effects of this resource

reduction were felt by the resident population, then its effects are likely to have been significant. The model shows a fall representing the loss of over 62% of the potential population over 500 years, and this could have resulted in starvation and/or migration, if the Mesolithic populations attained the values suggested by the model. Given our knowledge of Mesolithic mobility, it is likely that if this occurred, migration would have been the most likely vector for this loss.

When considering these figures, which address research **Aim 2** and **Aim 3** of this thesis, it is important to consider the fact that even though the model allows population potential to increase between 10,000BP and 9,000BP, the opportunity for increased population density may not be utilised. As observed by Jochim (1976) for his model, ethnographic hunter gather groups rarely exploit the resources to the full and often have a comfortable resource reserve in case of lean years. If the increased potential population density observed by the model for the coastal zone is considered to represent resource surplus, then it is possible that these coastal communities may have been buffered from the observed effects discussed above. In addition, this resource buffering could have presented opportunities for a move towards more sedentary occupation. However, given the scale of the models figures, even if resource buffering occurred, it is probable that the decrease in supportable population and coastline could have impacted upon these coastal communities.

The results in conclusion, show that the thesis has successfully generated models of food resources and their yield, thus achieving **objectives 2.1** and **2.2** of this thesis. In addition the evaluation of this data assists in the achievement of **objectives 3.1, 3.2** and **3.3**.

5.5 Model results: Introduction – Predicted areas

Whilst the tables and base resource and potential population maxima maps produced in the previous section are useful, greater information and detail may be gleaned by looking at the effect on an individual hunter-gather territory. Since hunter-gather populations are potentially mobile, it is likely that large scale changes in available land may impact on a hunter-gather group. However, by looking at the effect of the introduction of sea level rise to a set of predicted territories, we can begin to observe changes which may affect hunter-gather decision making. This section will present the predictive model. Following this, an analysis of resource catchment areas will be made. Further, by performing a catchment analysis upon the results, an indication of theoretical group size may be possible.

5.5.1 Model results: Predictive model

Upon examination of the quality of the datasets (Chapter 5), it was felt that only the southern area possessed sufficient data quality to permit modelling. Topographic data for this model was derived from the pick of the land surface in the seismic data, which was converted to depth and integrated within the GIS. The resultant output is provided in Figure 5.45. From this dataset, a slope model was created (Figure 5.46), with the lowest slopes being given the heaviest weighting (values below 5 degrees). Additionally, the topographic datasets also incorporated the relative sea level heights over time, as provided by Shennan (2000) for the study area. These were applied to the DEM generated from the topographic data. Areas derived from the 3D seismic data which fell below this contour

were then deemed to be submerged, whilst those above were considered to be land. The

combined results for the period 9,500BP to 8,000BP are given in Figure 5.47, whilst a

demonstration on the available landscape is shown for 9,500BP in Figure 5.48.

Since the fluvial features located in the seismic data are likely to represent the flood plain of

the river, rather than the channel itself (in a similar manner to that observed by

Pozamentier, 2000), it was considered that the distance from these features would be

sufficient to describe their effect on the model. Scores were therefore ascribed, which

placed the highest value in the floodplain itself, whilst the score decreased with distance

from this feature to a distance of 0.5km. Additional weighting was provided through the

use of the Strahler stream order (Figure 5.15, Chapter 3) to allow the model to consider the

river size. Once all the layers had been compiled and processed, the resulting outputs were

added together to allow a quantification of location. The results of this process for 9,500BP

are illustrated in Figure 5.49. The model can be seen to predict an area of optimal

opportunity for an area of a few 10s of metres, rather than a single location. As the model

only produces area data, the highest scoring areas were manually selected and converted

to point data to facilitate additional analysis (Figure 5.50).

What the model clearly illustrates is a preference for coastal locations, and specifically

areas of fluvial/coastal interaction. This is, perhaps, to be expected, given the weightings

within the model. Indeed, it is perhaps a limitation of this model in that it preferentially

predicts for site location in coastal areas and not in more landlocked zones. While this

initially may not seem a major issue, since preferential settlement is thought to have

occurred in these areas, the very high values effectively mask areas of interest in the inland

areas which may have equal archaeological validity and interest. One possible solution to

this issue, if more time was available, would be a second iteration with the coastal element

of the model removed. Foley (1981) presents the possibilities of considering "off-site"

archaeology, and a combination of this with the model, would facilitate a more balanced

prediction.
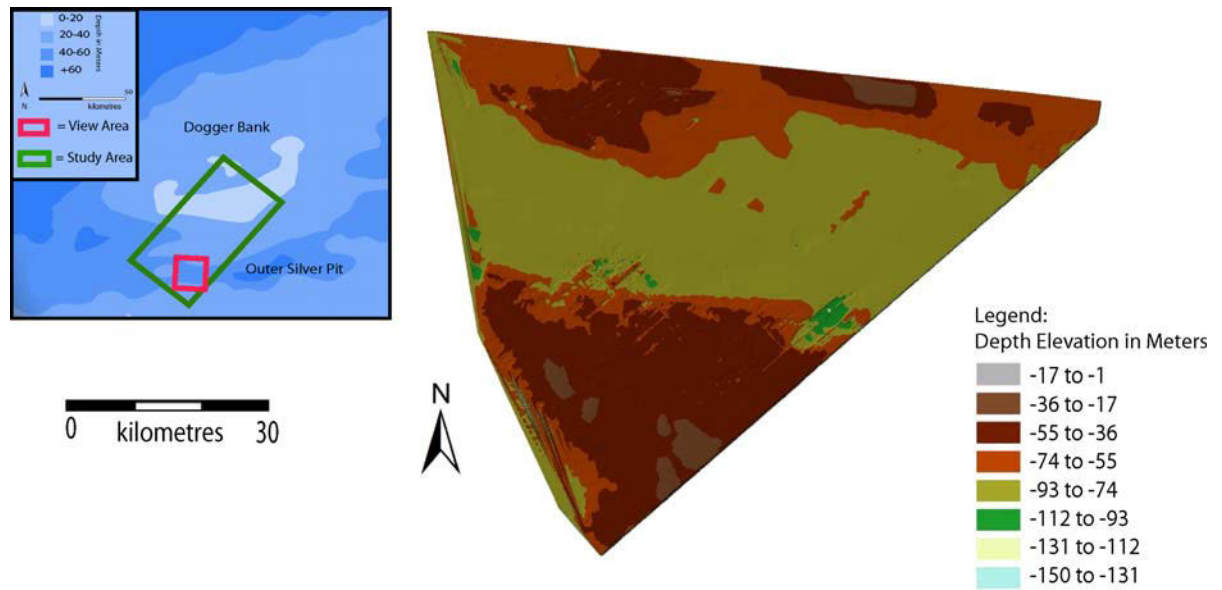
Figure 5.45 Surface model of the topography of the southern part of the thesis study area.
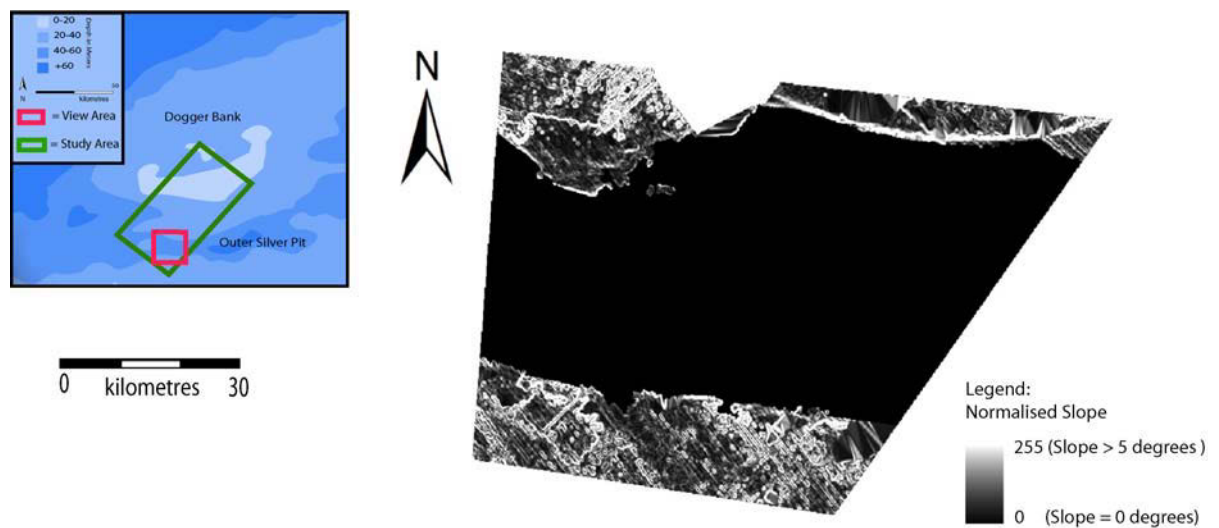
Figure 5.46 Normalised slope model for the study area.
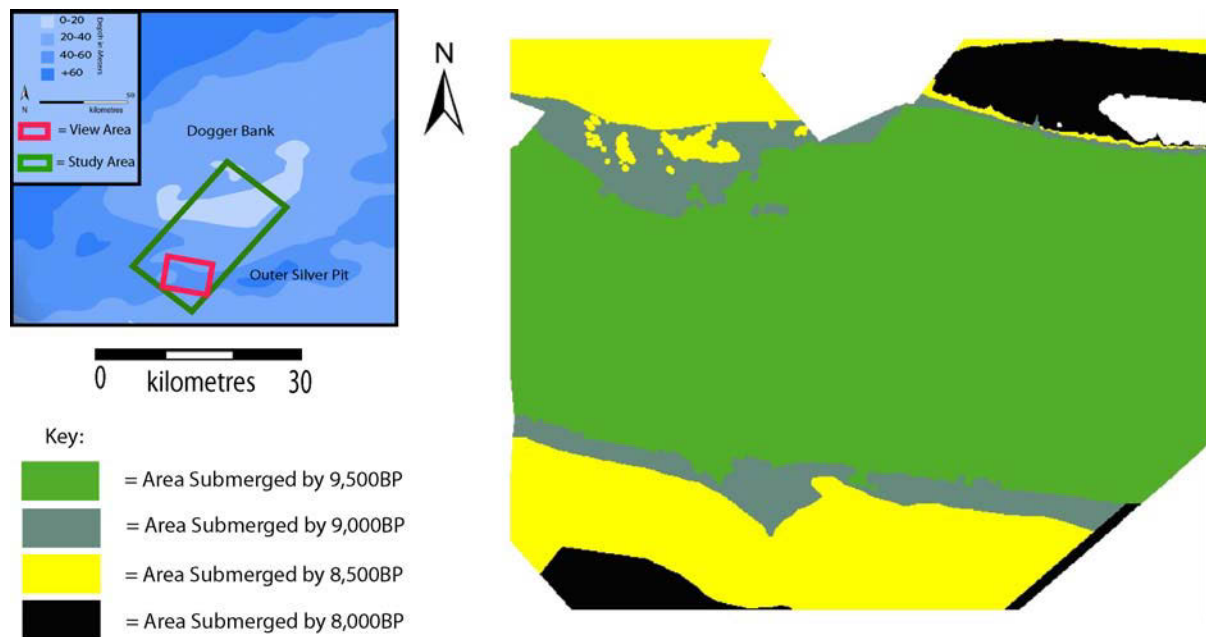
Figure 5.47 Sea level rise model for the study area from 9,500BP (Green) to 8,000BP (Black).
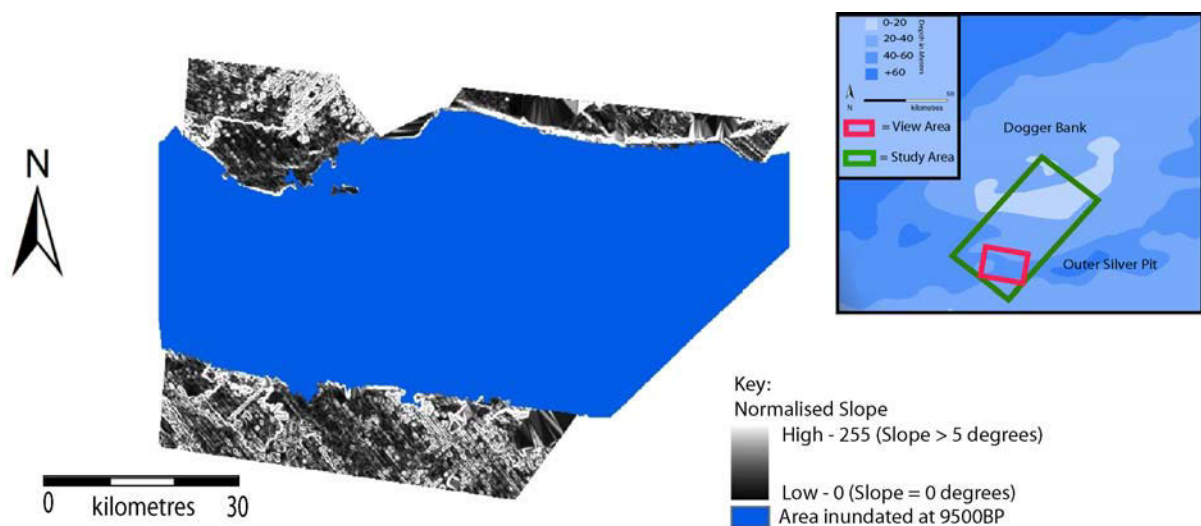
Figure 5.48 Inundated area at 9,500BP overlain on the slope model.

Figure 5.49 Uninterpreted output of predictive model at 9,500BP through the combination of the data layers. Note that whilst river valleys and the coastline score well (Shown Purple), the areas most likely to be locations of archaeological sites are the junctions of rivers and small islands.
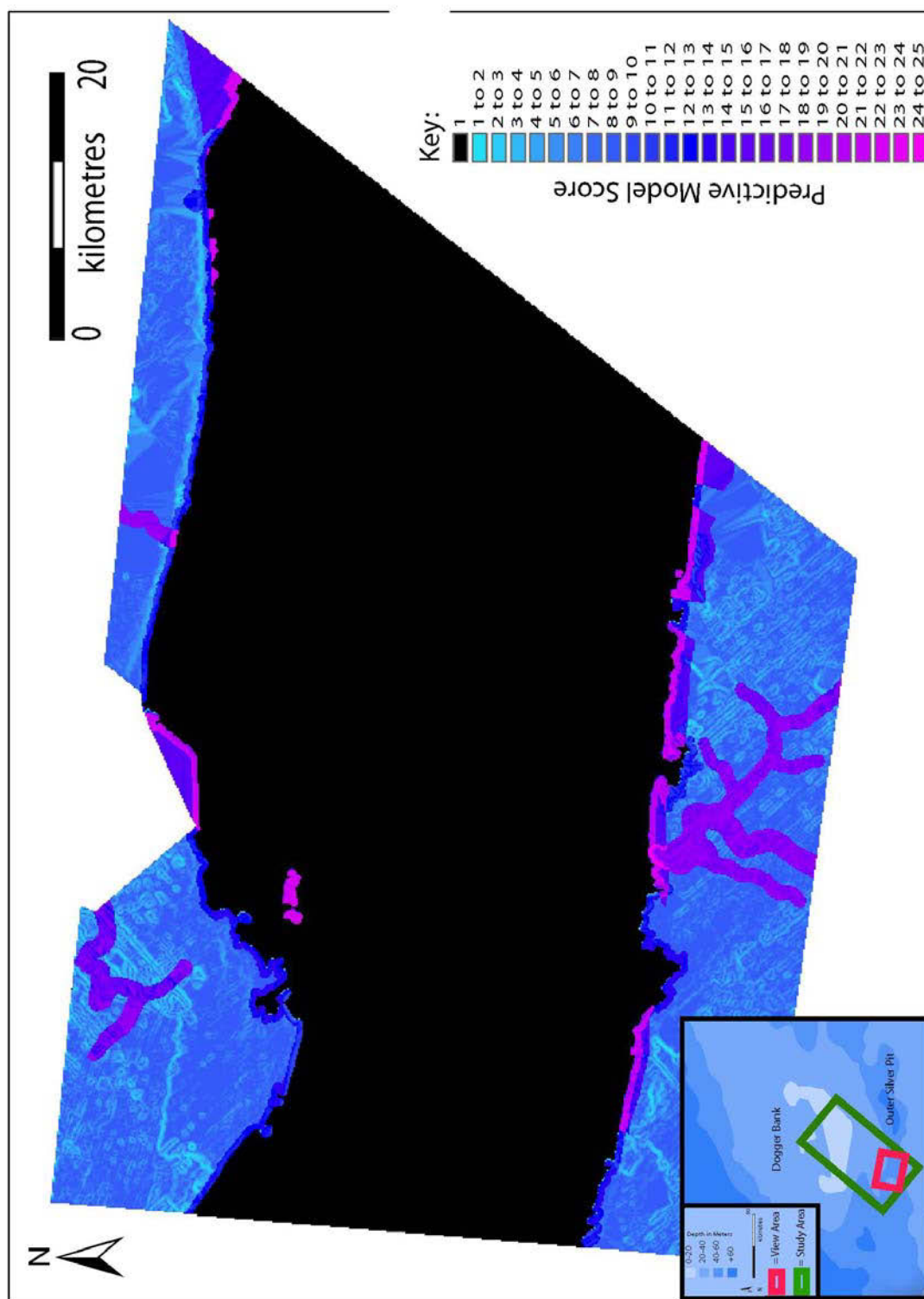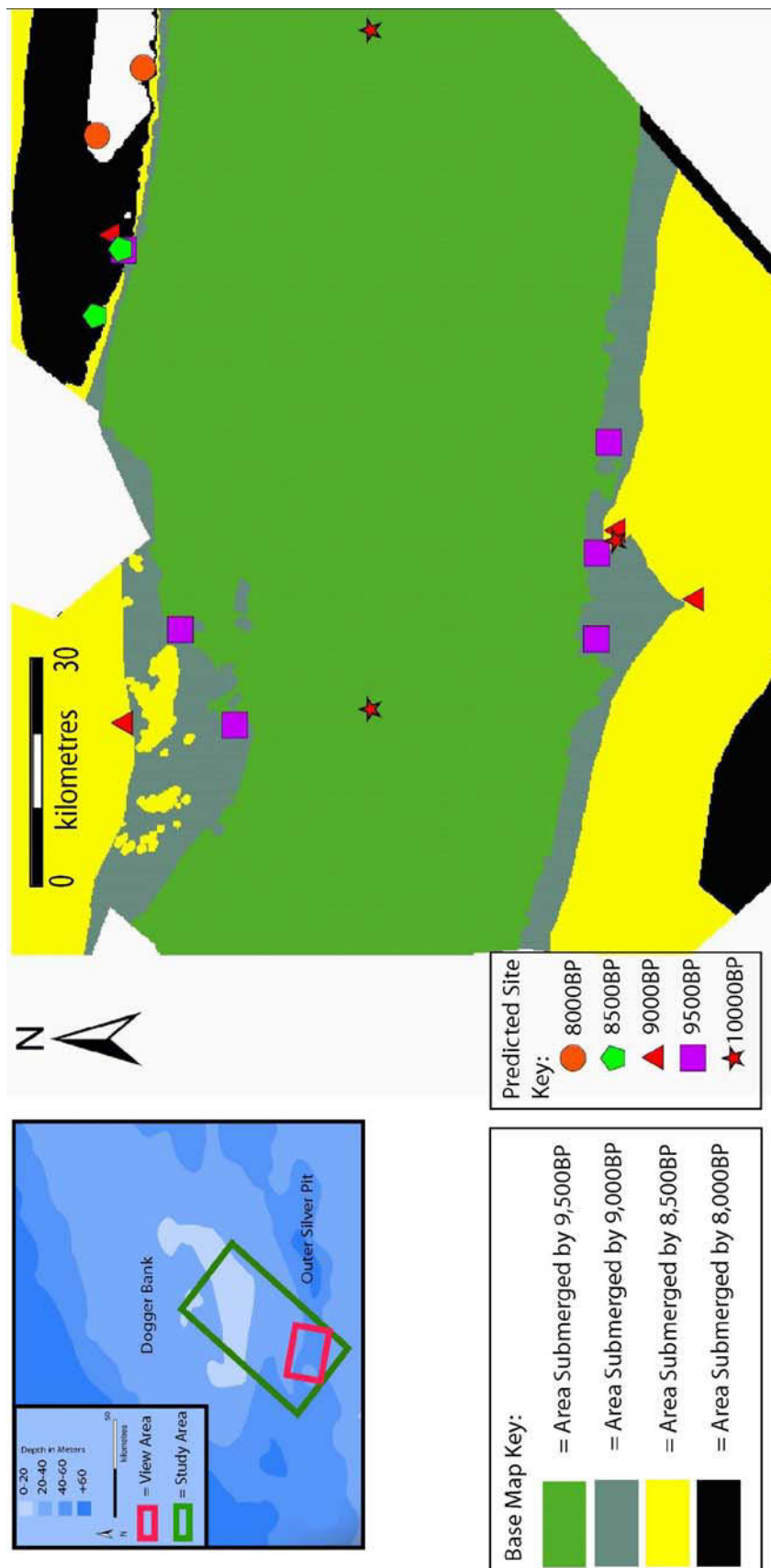
Figure 5.50 Predicitive model output (by period) after conversion to point data.

5.5.2 Results from the catchment analysis

Whilst the prediction of archaeological areas of interest is useful in terms of prospection, it can also be used in conjunction with catchment analysis to allow for a more thorough analysis of resources available to predicted areas. This analysis is useful, since it allows for a consideration of elements not possible within the simpler predictive model. Therefore, the methodology used in this thesis (Chapter 4) considered the need for the study to use catchment analysis as a way of combining both the results of the qualitative model and the predictive model. This would be achieved by utilising the resulting predicted sites as the centres from which site catchments could be calculated and then overlain onto the qualitative map results to produce a resource result for each predicted site. As such, the resultant resource information facilitates the possibility of examining the resource and relative support mechanisms at each site.

To allow for a more realistic modelling of the terrain costs, a dynamic terrain coefficient was used, which varied according to the vegetation and soil type in a fashion similar to that prescribed by Givoni and Goldman (1971), with marine areas being ascribed a co-efficient of 1.0 to allow a partial modelling of marine transport (see Figure 4.8).

Once the base of the model had been constructed, the cost of travelling from all the predicted areas was then calculated. Through the reclassification of the resultant catchment shapes into Boolean masks (see Figure 5.51), it becomes possible to select the relevant data from the environmental model (see Figure 5.52 and Appendix 2). This subset of the environmental data is effectively the amount of resources available to any occupants

246

of a given predicted area at a specific time. As the subset contains the resource

information, a calculation using the values for human energy requirements allows for a

calculation of the maxima population size as well as to allow for relative comparison of

productivity between predicted areas.
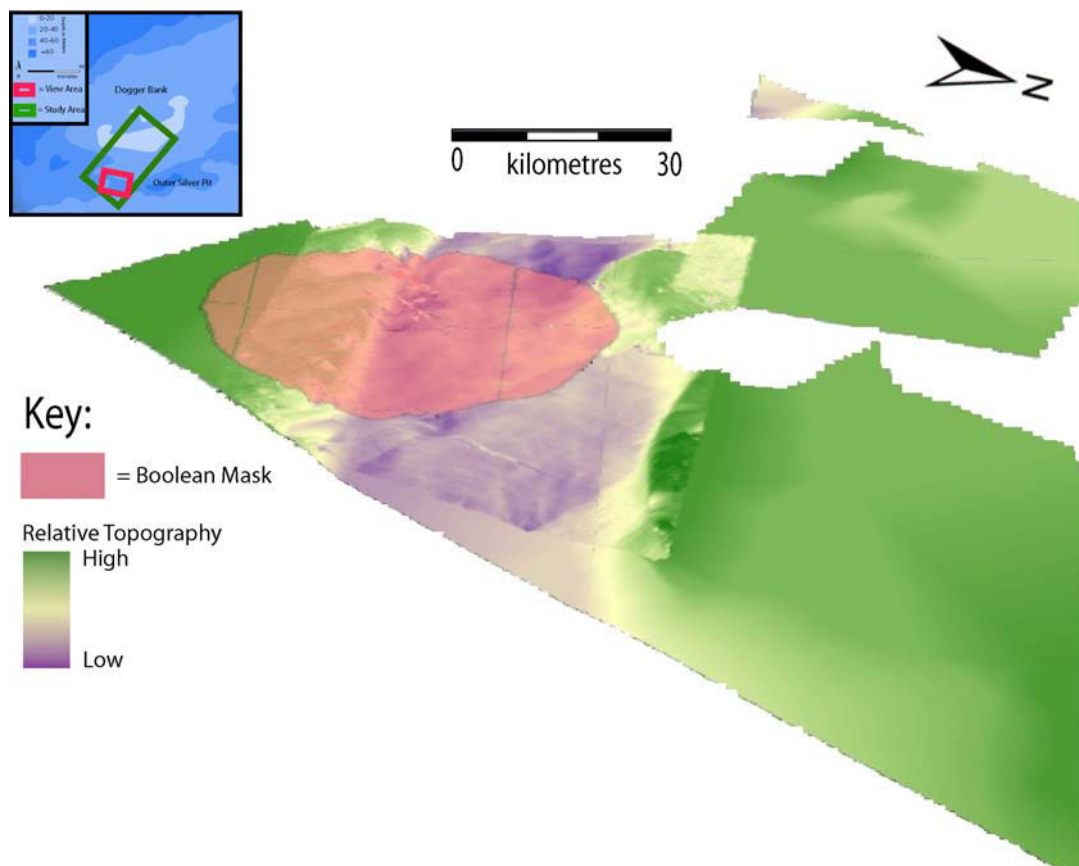
Figure 5.51 An oblique view of the Boolean mask for a territory overlain on the terrain

model for 9,500BP.
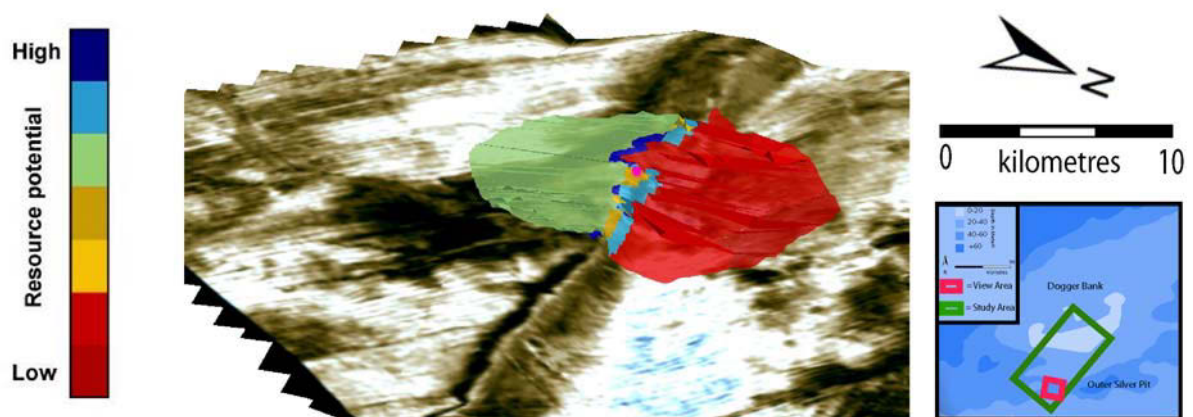
Figure 5.52 Selected resource data from the qualitative model using the boolean mask for the site as Figure 5.51. The predicted site is shown here as a pink dot, note that this does not sit on an area of high potential, due to this being a wetland area. Rather the site sits on a small patch of high ground. The resource potential colour bar is relative.

(Images of all the resource data areas selected by catchment analysis can be found in Appendix 2)

5.5.3   Analysis of the catchments

The results of the predicted catchment data derived from the qualitative model is given as tables in Appendix 1. The results for potential population density within the catchment are also displayed graphically in Figure 5.53, and for maximum potential catchment population (Figure 5.54). If the results for maximum catchment population potential is examined first, it can be seen that the maximum potential population is proportional to the catchment area and further that the time intervals after 9,000BP show some of the smallest catchments and potential populations. In view of the increasing marine inundation during these periods, this result is not surprising given the small area of habitable land available to these groups.

There are some notable outliers to the general trend which relate to 9,000BP. If we look at one of these in more detail, their anomalous nature is more understandable. The most pronounced outlier in these results is the area "9k-1", which has a very small territory area, but a high level of resource availability and hence the potential to support a high maximum population. At first inspection this would be anomalous, however, it is clear from Figure 5.55 that the area is located along the coastline, and therefore has access to marine resources that facilitate potentially higher population numbers. This is especially enhanced where there are numerous islands surrounding the area. Since the catchment analysis allows for travel over water, the island resources become accessible to these populations. As the island has a very high percentage of coastline, this further accentuates the marine resource utilisation, and thus causes the anomalous catchment/ population potential relationship. If these results are grouped to produce an average catchment/population potential result for each temporal interval, it is possible to see the changes in the average group size over time (Figure 5.56). It is apparent that the average catchment size largely falls within the range of 60 to 40 km^2. However, there is a considerable variation in the potential population size. Large supportable population potentials are present at 10,000BP and 9,500BP, however, these potentials fall between 9,000BP to 8,500BP. This situation is explained, primarily, by the use of a subset area, which cannot, by its restricted nature, allow a consideration of the resources in other nearby areas. At 8,000BP the catchment population potential rises, but is less than that for the whole study area. This insight is interesting, since it suggests that for 8,000BP that whilst the overall maximum supportable population density significantly rose per square kilometre, the actual local perception of this rise may have been significantly less.

There also appears to be a clearer temporal grouping. For example, the results for 8,000BP

cluster together with maxima potential density of 1.2, even though the territories range

from 24km^2 to 47km^2. An averaging of these results produces a result that is comparable to

that of the maximum potential population numbers.
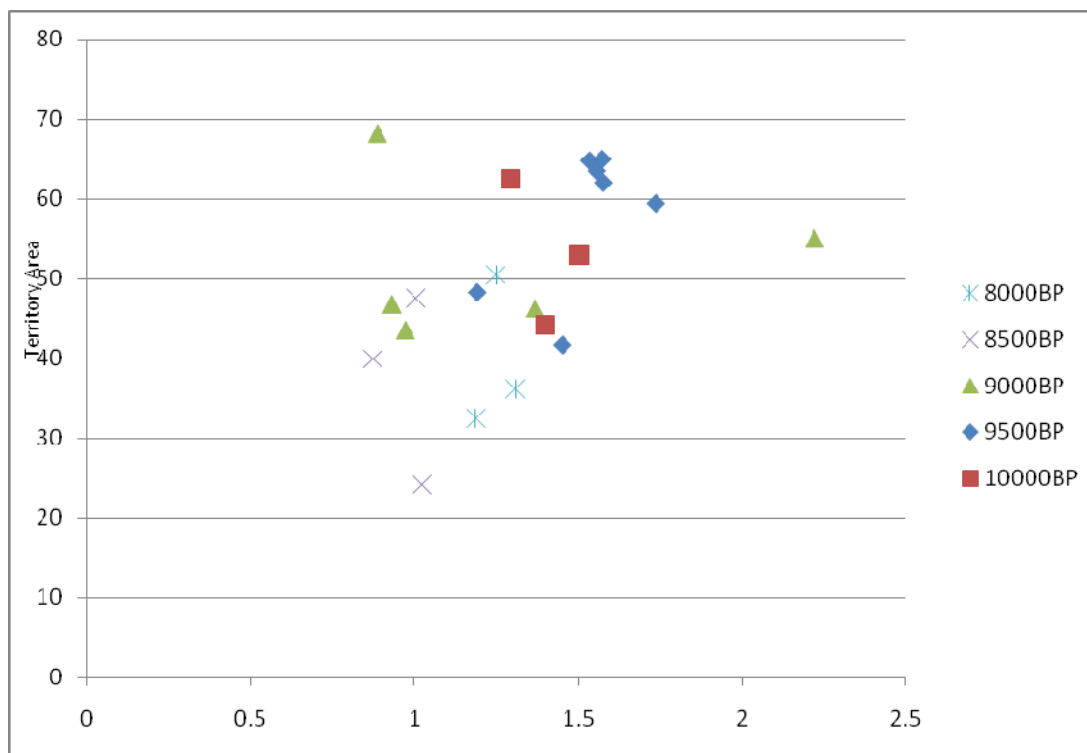
Figure 5.53 Overall Catchment and Qualitative model results plotted as Territory area Vs Maximum Potential Population Density.
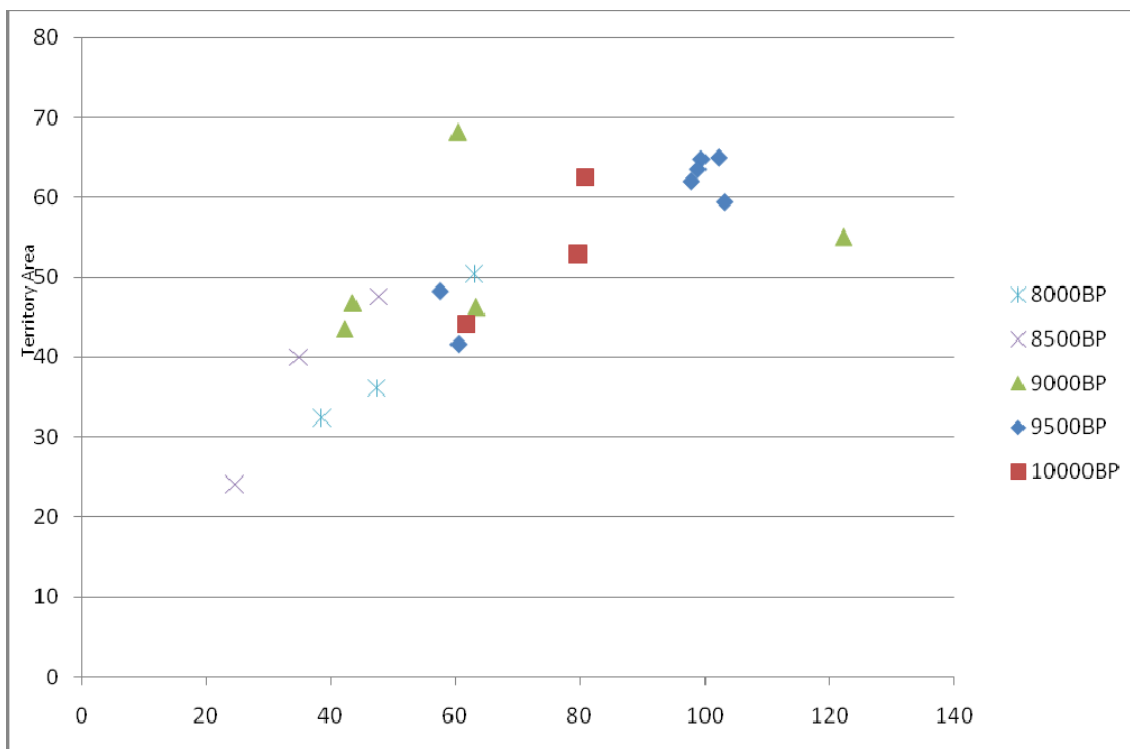
Figure 5.54 Overall Catchment and Qualitative model results plotted as Territory area Vs Maximum Potential Population Size.
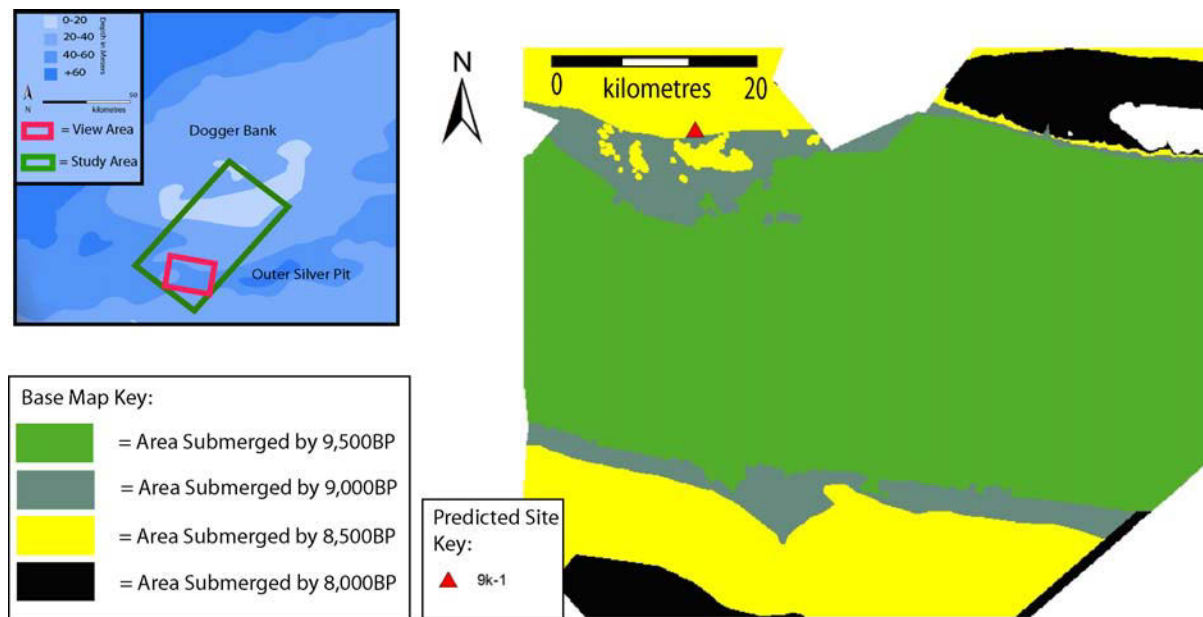
Figure 5.55 Location of predicted area "9k-1".
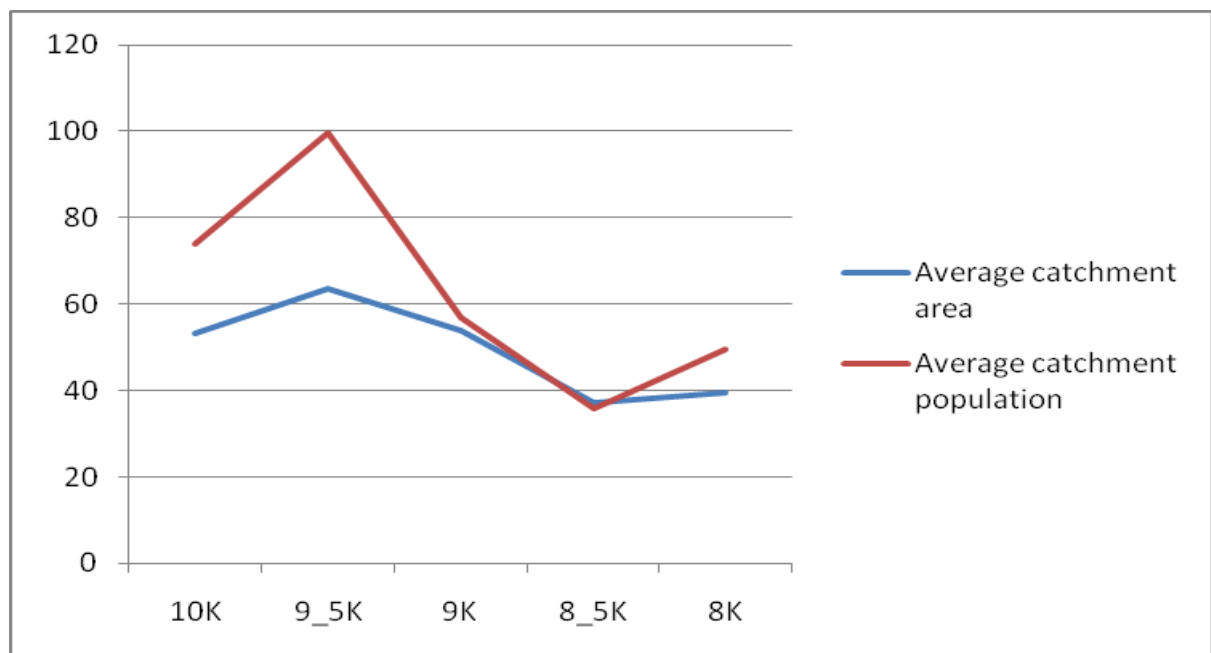
Figure 5.56 Average catchment size and Average catchment population over time.

5.5.4 Resultant site catchment analysis of predicted sites: Summary

The analysis has demonstrated that it is possible to apply the principles of predictive modelling within submerged areas of the southern North Sea. As such, it can be seen that these results achieve **objectives 2.3** of **Aim 2** of this thesis by producing a model that models the location favourable areas for habitation. The resultant model has shown its ability to identify hypothetical optimal areas in a range of landscape environments throughout the temporal and spatial changes under examination. Indeed, the model can be seen to be operating successfully through its identification of an optimal environment not observed in the initial examinations of the landscape, nor in the whole study area qualitative model. The results of the predictive model have provided additional insight into the results of the main qualitative model and achieve **objectives 2.4** of **Aim 2** of this thesis. The results also have allowed the examination of the effects of landscape loss at a catchment level, thus achieving **Objective 3.3**. This more localised perspective, whilst broadly reflecting the results of the main model, illustrates that the support conditions for human population are complex. Indeed, the fact that the qualitative site catchment results of supportable population density are some 85% (for 8,000BP) less than that predicted by the main qualitative model is a highly unexpected result.

5.6   Synthesis

The generated soil map, being the first of its kind for a submerged landscape, has provided important information that has allowed the effective modelling of the conditions of the landscape for that region. In the absence of such a critical dataset, it unlikely that results of this thesis would have been achieved so effectively. Indeed, the resulting map of dominant woodland type has provided invaluable insights into the changes experienced in the study area during the marine inundation. Perhaps the most significant finding from this, is the identification of a major woodland split at 8,500BP. The division of the north and south of the study area by marine transgression, and its reflection within the woodland maps is an unexpected, but important result. This information, exclusive of the model, provides a new perspective on this landscape. Indeed, the result of such a division across a marine area is such a significant difference, that it must have had social implications for the occupants of this landscape.

As the utilisation of different food resources is often a mode to support differing cultural identities (Milner 2006: 61, Parker Pearson 2003), such a fundamental polarisation in food resource would probably be sufficient to produce this differing cultural identity. The idea of different cultural identities in the North Sea area during the early Mesolithic is supported in part by Kooijman's (1971, 1985) observations of typological differences between material from Brown Bank in the North sea, and surrounding regions, which suggest that such a proposal would not be inconsistent with the present evidence. This idea will be discussed further in Chapter 6 and will address **objective 3.4** of this thesis.

The results of the qualitative model are both expected and unexpected. On the one hand, the overall loss of landscape and population potential from this region, due to inundation, is a predictable result. However, the significance of the qualitative model in this situation is the revelation of the rate and scale of the change. Rather than a slow, steady downward progression, as logic perhaps would expect, the qualitative model reveals a more complex picture. The rapid rise in population potential between 10,000BP to 9,000BP in the face of landscape loss reveals that the marine inundation could have presented opportunities to the resident population, rather than a disaster. The model illustrates that when a marine coastline appears in the landscape, the benefits of it to lifestyle through increased aggregation potential are significant. Indeed, it is only when a significant proportion of the landscape is lost, and the coastline length drops, that the negative affects of the inundation upon the population potential become apparent. The effect of this opportunity, then shortage upon the Mesolithic population of the region is likely to have produced a noticeable cultural effect, especially given the magnitudes of change illustrated by the qualitative model. This can be seen in major changes not only in the overall potential population maxima, but also the density of occupation.

The results of the predicative model support the findings of the qualitative model that the coastal areas are significant. The results of the analysis of the population support capacities of these predicted areas represent an important result in addition to a valuable local perspective. Whilst the catchment result is similar to that of the overall study area, it is apparent that the mixed terrestrial/marine resource procurement strategy of the nearshore zone for 9,500BP to 9,000BP provides an opportunity for much greater population

aggregation and stability. Clearly then, this represents a period at which more sedentary

behaviour would be likely.

The utilisation of the qualitative model results within the landscape has proved effective in

assessing the significance of the environmental changes modelled. From the environmental

information alone, it may be determined that the shift in environmental conditions at

8,000BP is a very significant factor, given the potential increase in resources.

Therefore, whilst representing a slight regional rise in population potential, this is a much

less significant result. The overall landscape loss and low population at that period mean

that the environmental shift did not result in significant changes. Conversely, through the

cross analysis, the rise in winter of both the population potential and support density

between 10,000BP and 9,500BP is apparent in both the whole study area as well as locally.

This finding suggests that the rise would have been observable and that the opportunity to

exploit this existed. If this scenario occurred, the result would have potentially seen an

increase in the population size and density on both local and area scale across the whole

study area. The effects of such a change in population potential therefore, are likely to

have been felt, and these results will be discussed further in the next chapter.

CHAPTER 6

DISCUSSION

6.1   Introduction

The previous chapter presented a model of the resources for the archaeological landscape within the southern North Sea study area. The model considers multiple food resource types, which can be used to present maxima values for the supportable Mesolithic population of the area. Additionally, a model which attempted to predict the likely areas of occupation within this landscape, based upon these data, has been presented. Both the resource and predictive models have provided a number of important insights into the effects on resources and supportable population due to marine inundation and landscape change.

As shown in Chapter 2, Doggerland has been proposed as the heartland of Mesolithic Europe, but as illustrated in that chapter, direct evidence for this is greatly restricted by the level of understanding of the landscape. Through the use of seismic data (Chapters 3 and 5), it has been possible to build a new picture of the landscape. The subsequent modelling and analysis of this landscape has made it possible to provide maxima determination of Mesolithic occupancy in this region based on the nature of the potential economic resources supportable from these environments. Whilst the model results presented in Chapter 5 do not provide an absolute quantitative determination of population values, the model provides information with which effects of the marine inundation and the loss of this Mesolithic heartland can be considered and discussed. By considering the implications of

the results, gross trends in the mode and possible style of occupation could be postulated. These significant key findings will now be considered in light of the Mesolithic record surrounding the study area.

The formation of structures such as Howick at around 8000 cal BC will be considered with respect to this information. Waddington *et al.* (2007) suggests the Howick hut to be a social response to landscape losses in Doggerland. The results provided by this thesis will allow for a discussion of this idea in light of the findings provided in Chapter 5. Beyond this, the effects of the landscape loss will be considered not only locally, but also on a wider European scale. Beyond the obvious negative effects, such as territory loss, as illustrated in Chapter 5, new opportunities in both resource and social aggregation terms were seen to have presented themselves to the groups affected by this change in landscape.

6.2   Discussion: The significance of the Outer Silver Pit

Perhaps the most significant feature identified within this thesis is that of the Outer Silver Pit. Marine incursion of this feature could be argued as having important ramifications for understanding how the Later Mesolithic in Europe developed. The results of Chapter 5 show that the inundation of this feature had a strong positive cultural influence. In terms of effect, this may even exceed in importance the final submergence of the landscape. Evidence used in this thesis (see Chapters 3 and 5), and from other studies (Fitch *et al.* 2007, Gaffney *et al.* 2009), suggests the prominence of the Outer Silver Pit as the *axis*

cruces within the Mesolithic landscape (Appendix 3), and, perhaps, even for the North Western European Mesolithic culture.

The erosional truncation observed by Briggs (2007) that provided part of this evidence can also be seen in datasets obtained for this thesis (Chapters 3 and 5). Both the Gauss 195B 2D survey obtained from the BGS and also 2D sub bottom profiling information over the Outer Silver Pit, obtained for this thesis from the University of Bremen, clearly shows this strong erosive truncation. Briggs (2007), in addition, observes evidence from large early Holocene sand banks, outside of this thesis area, which clearly provided her with the evidence that the Outer Silver Pit was a macrotidal environment. Further direct evidence of the strong tidal currents can be seen in the 3D seismic data contained within the thesis study (Gaffney *et al.* 2007, 2009). Within this, the shape and considerable size of the scouring of the base of the Outer Silver Pit, caused by this tidal environment is evident.

Comparable macro-tidal environments, including the Severn Estuary, have a tidal range of some tens of metres (Bell 2007) and high tidal speeds. Such figures have significance, especially when considering the sea craft available during the Mesolithic. For example, a theoretical crossing across the channel is illustrated in Figure 6.1. It is apparent that a direct crossing (from A to B) would have been difficult. Under such conditions, skill would have been required to have crossed to a specific landing point successfully. Whilst making direct crossing difficult, it is important to also consider the fact these tidal currents would have changed during certain times of the year, possibly making it easier to cross. Thus, with the changing nature of the Outer Silver Pit from a large lake (10,000BP), which was

relatively easily crossed, to that of a tidal estuary (9,500BP), it is probable that the nature of

Mesolithic social contact may also have changed within this area. This is significant to our

understanding of the archaeology of the region. Earlier regular contact facilitated by the

lake would have changed to a more tenuous contact, which may be more related to trade

and prestige, rather than regular communication which have occurred in hunter-gatherer

communities. If this is considered in the light of dense and increasing coastal populations

forwarded by the results in Chapter 5, it suggests that the local Mesolithic culture would

have been strongly influenced by landscape changes. Given the importance of the region to

the European Mesolithic as a whole (Clark 1936, Coles 1998, Chapter 2), these changes

must, therefore, have had an impact on human occupation and behaviour throughout the

region.
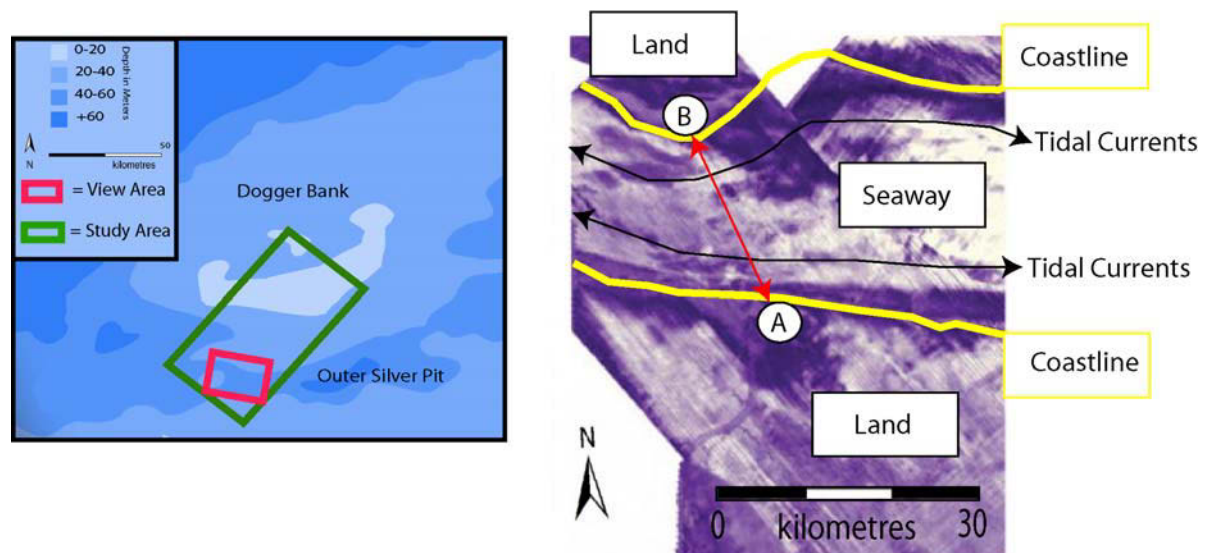
Figure 6.1 The Outer Silver Pit seaway. A potential crossing between points A and B would
have been a considerable task, given the strong tidal currents that would have been present
within the seaway.

6.3   Discussion: The Outer Silver Pit and its place in Europe

As shown in the previous chapter, the landscape surrounding the Outer Silver Pit would

have been densely occupied. When we consider the surrounding archaeological record, it is

likely that many Mesolithic populations (e.g. Scotland and Norway) are derived from this

region (Coles 1998, Warren 2005, Chapter 2). It is, therefore, apparent that understanding

the changes within the Outer Silver Pit is critical, not only to understanding its place in the

European Mesolithic landscape, but also to the development of Mesolithic north western

Europe as an entity. Further, if the theory advanced by many Mesolithic scholars is correct,

and rivers and streams formed the major routeways through which Mesolithic peoples

moved around the landscape, then the importance of the Outer Silver Pit upon the

Mesolithic is increased (e.g. Bell 2007, Waddington 2007, Schulting and Richards 2000). To

support this, if we examine a map of the Mesolithic landscape for 10,000BP, generated

using data from this thesis, Gaffney *et al.* 2007, and unpublished work on the Dutch Sector

by the author, it can clearly be seen that all the rivers in the region flow into the Outer

Silver Pit (Figure 6.2). If we now consider the rivers as routeways, then it is apparent that

there is a major convergence in the Outer Silver Pit. Therefore, the Outer Silver Pit acts as a

central node within the communications network of the Mesolithic, linking the landmasses

of the UK, Doggerbank and parts of Europe. As a central node within the network, the area

is, therefore, an obvious location at which aggregation would naturally occur.

As a lake, the Outer Silver Pit would have formed a water area exceeding Lake Pickering in

size. Indeed, the open vista provided by the presence of the lake may have made location

and contact with other groups far more possible. It is, perhaps, significant that it is at a lake

side at which the famous site Star Carr is located. With the presence of significant

resources provided by such a lake, aggregation could have been possible throughout the

year. The results of population support calculated for the period 10,000BP from Chapter 5

suggest that this would have been possible, especially during the summer and autumn. At a

more simplistic level, travel across the lake would have been relatively easy, given the

relatively low current regime and lack of tides. Travel would have been largely limited by

the weather, and, when this was favourable, travel even by the simple log boats of the

period must have been possible (Pedersen *et al.* 1997). The relative ease of travel must

have stimulated trade and contact between communities who visited this region (Gaffney

et al. 2009). It is interesting to note that during this period, cultural indicators are

suggestive of links. These include the rare antler head dresses, which are observed from

Bedburg-Konigshoven in Germany (Street 1989), through the Low Countries (Verhart 2008)

and as far North as Star Carr (Clark 1972, Conneller 2004). Similar links are suggested for

microliths (Jacobi 1976) and barded points (Verhart 2005, 160). David (2006) suggests that

both antler frontlets and barbed points offer the ability to discern a "northern

technocomplex" centred on the North Sea (David 2006, 139).

The site of Star Carr on a lake edge suggests that large lakes within the landscape, and the

presence of water in general, may have been foci for religious offerings (Milner 2004). This

is in addition to the more simple virtues of offering a locus for travel and trade. Whilst such

religious activity is likely to be present, it is likely to have occurred at low levels in areas that

the inhabitants would have deemed special. One such significant place, where we might

expect such activity, is the main lake drainage channel of the Outer Silver Pit (Figure 6.4).

262
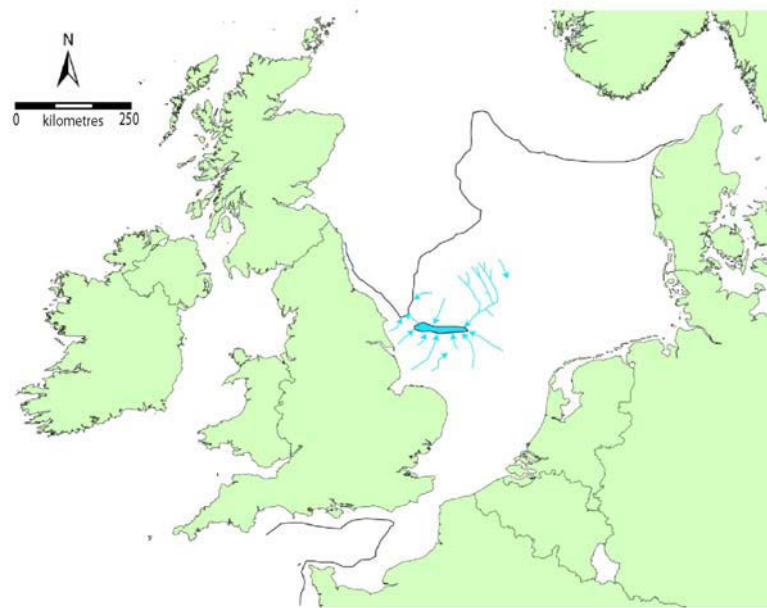
Figure 6.2 The Outer Silver Pit during the Earliest Mesolithic period, at this time the Outer Silver pit would have formed a lake. Note that significantly all the rivers in the region converge there (Fitch *et al.* 2007 and Gaffney *et al.* 2009).
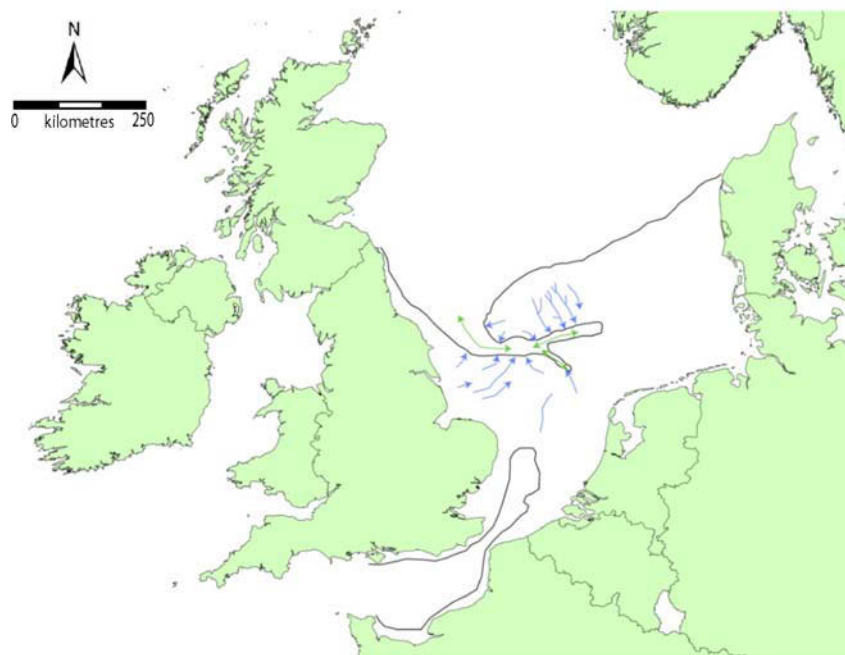
Figure 6.3 The Outer Silver Pit in the later Mesolithic, during its estuary stage. Many of the rivers in the region can be still seen to congregate there (Fitch *et al.* 2007 and Gaffney *et al.* 2009).

Figure 6.4 Coles (1998) map of the Outer Silver Pit lake.
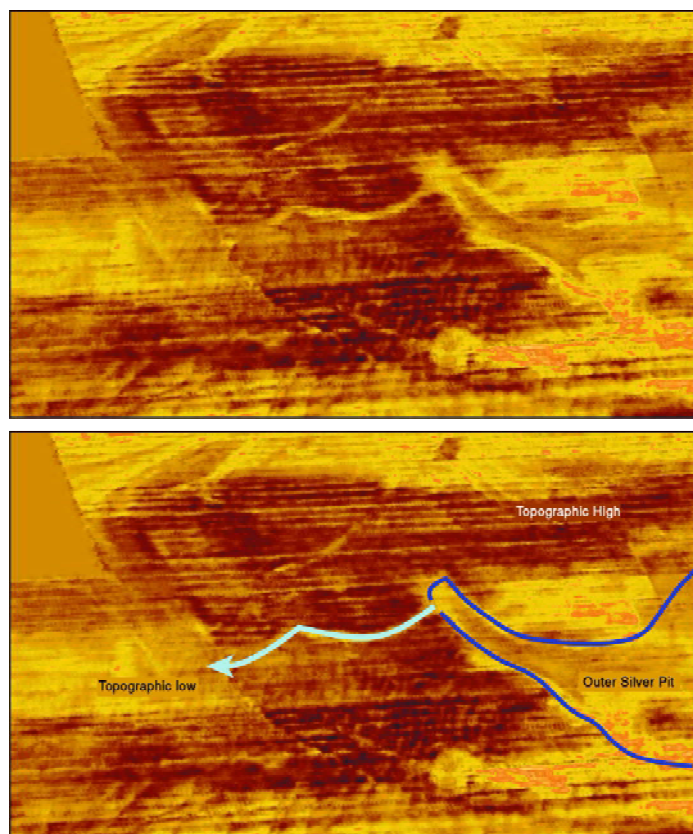
Figure 6.5 Image taken from Figure 7.9 in Gaffney *et al.* (2007) – the interpretation of the channel feature is an outflow from the Outer Silver Pit lake.

This feature was first hypothesised by Coles (1998), however, the speculative nature of her

maps would obviously have prevented Coles at guessing at the importance of the Outer

Silver Pit. The first direct evidence for such a channel was observed in 3D seismic data by

Gaffney *et al.* 2007, and represents a deeply incised channel (Figure 6.5). This channel can

be demonstrated to have flowed from the Outer Silver Pit out towards the area that would

have formed the North Sea at that time. What is significant about this is that it provides

access to the sea from the Outer Silver Pit, thus, the channel would have presented a

routeway into the Outer Silver Pit from other areas of North Western Europe in the

landscape (Fitch *et al.* 2007).

As can be seen in Chapter 5, the data for dominant woodland clearly shows an

environmental segregation across the Outer Silver Pit. If we consider these factors in

parallel with a physical separation, due to a macrotidal environment, it suggests that it

would be almost impossible that the separation of such large areas within the landscape

would not have had a cultural effect. This does not mean that Britain was necessarily

separate or isolated from communities on the continental landmass, nor the emerging

island of the Doggerbank (Figure 6.3). Rather, the landscape changes, and coupled

environmental changes, facilitated the mechanism by which differences between the

communities could occur. Further to this, the changes in environment and landscape

affected the resources which supported population. With increasing availability of marine

resources, and loss of terrestrial resources, the impacts on the occupants of the

Doggerbank islands were likely to have been significant enough to require a social

response.

The results in Chapter 5 show the possibility of a divide in population between a dense, but small, coastal community, and a larger, but much more widely spread, inland community. The results are reasonable, especially considering the occupants of this landscape have been proposed as the progenitors of the Mesolithic cultures of Norway and Sweden (Bang-Andersen 2003, Warren 2005), where such a separation in peoples is suggested (Nordquist 2000, 227) . If we consider this information in light of the landscape, some obvious divisions can be drawn. The Doggerbank island, would have had a very small interior, but large expanses of coastline, thus it is likely that a more coastally based culture would have predominated. Conversely, on mainland Britain and Europe, only a thin veneer of coastal populations existed, surrounded by more terrestrially based communities.

If this supposition is correct, then an impact of this landscape level division upon the Mesolithic populations of this region must be expected. If we examine the map of the landscape for the period 9,500BP and consider the dominant landscape features within the region (Appendix 3), it is possible to discern that it is clearly divided into three major regions (Figure 6.6). The Outer Silver Pit itself forms a major barrier between the Doggerbank (3) and the extension of the British landmass (1). However, there is an third and further, significant division that can be made. Recent unpublished research has been performed by the author in the Dutch Sector, utilising similar landscape location techniques as this thesis. This has revealed the presence of major river systems and an extensive river delta (Figure 6.7) near to the current median line. Such an extensive and prominent feature in the landscape would have formed an obvious boundary.
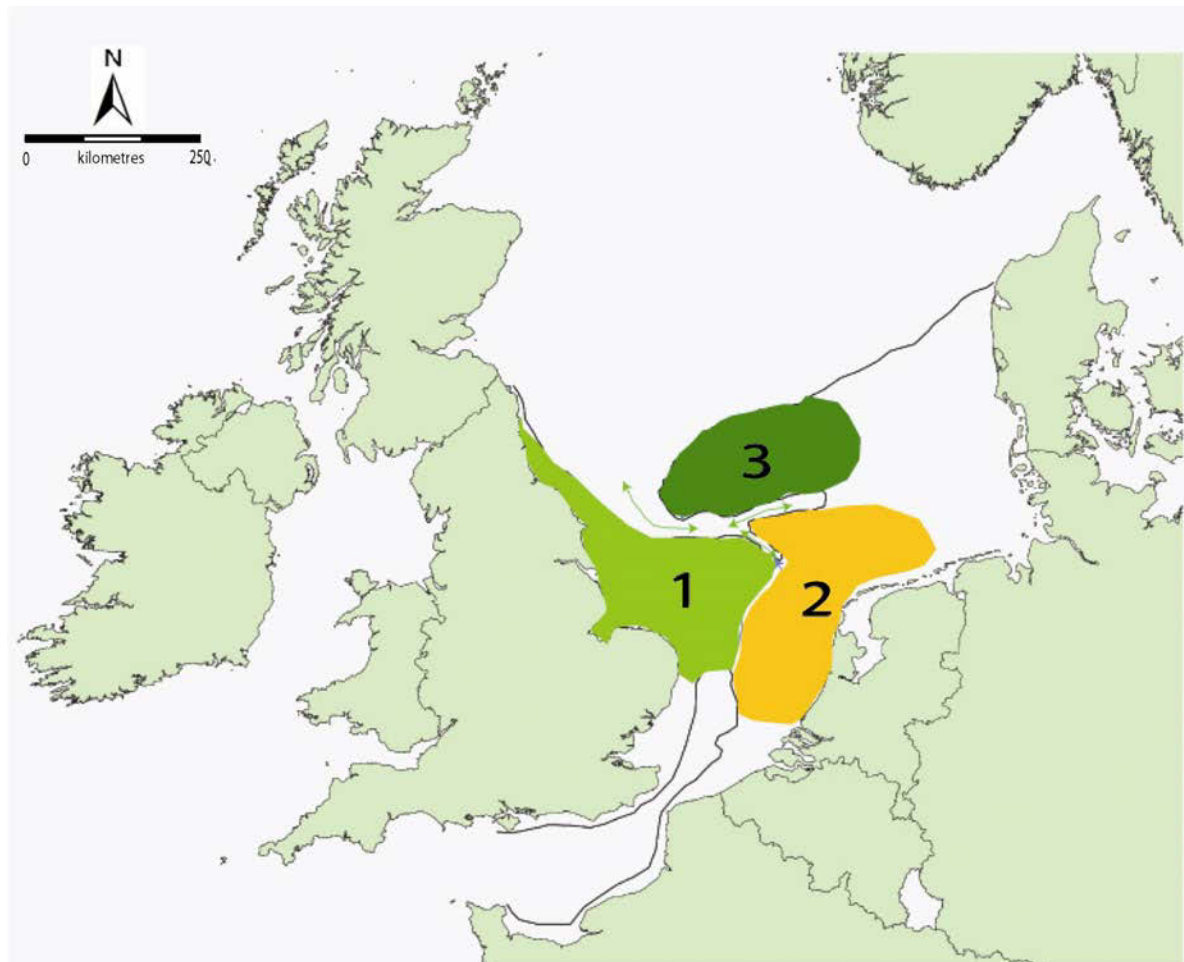
Figure 6.6 Possible social division due to the landscape characteristic. The exact dividing line between zones 1 and 2 is not definitive, but given the physical barrier of the major rivers and deltas (Figure 6.7) between the two zones a division line in this area is likely.
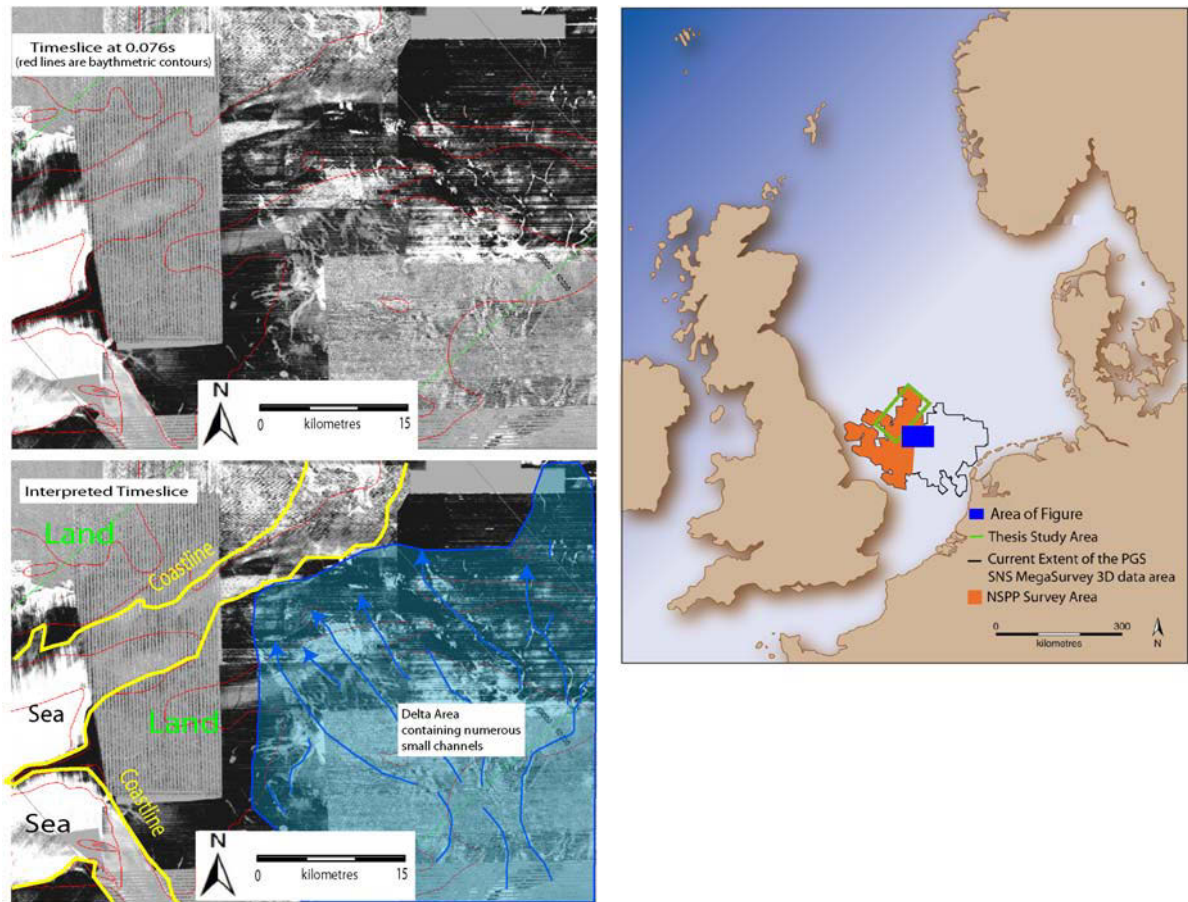
Figure 6.7 Seismic image from the author's current research in the Dutch sector of the southern North Sea. The black/white mottling shown in this region clearly shows the presence of an extremely large delta that extends to the flanks of the Outer Silver Pit within the Dutch sector.

Based on this information, and an extrapolation of the results of this thesis, it is possible to suggest that at the very least, a minimum of three separate groupings might eventually emerge.

If we look at these landscape areas in turn, the divisions in the landscape are significant. For example, there is a north/south division present in both physical and botanical terms. The results of this thesis (Chapter 5) suggest that the dominant woodland in zone 3 of Figure 6.6 would have been elm. Yet, for zones 1 and 2 of Figure 6.6, the woodland would

have been dominated by oak. Such a difference in vegetation cover and climax woodland

would have affected the resources of zone 3's flora and fauna, and a different resource

procurement strategy may have been required. If the landscape is examined in terms of

the morphology of the landscape at 8,500BP, differences between the zones are more

apparent. Zone 1 of Figure 6.6 is dominated by large river floodplains within a relatively

gently sloping plain. This plain would have been punctuated by low round hills (Gaffney *et*

al. 2007, Appendix 3). In contrast, the area of zone 2 in Figure 6.6 would have been

strikingly different. As the data in Figure 6.7 shows, the area would have been dominated

by a huge delta and its associated river systems. By way of contrast, zone 3 would have

represented a relatively large island separated from the mainland by a minimum of 40km.

It is therefore likely that the mode of hunting and lifestyle would have been different in

these areas. Whilst this cannot be quantified, the results of the model suggest that a strong

dependence on marine resources should be expected for zone 3 of Figure 6.6.

The Mesolithic groups located on the promontory, formed by what is now the Doggerbank

(marked as zone 3 on Figure 6.6), would have become isolated as marine inundation

progressed. This difference may have been further emphasised by the dominant

woodlands (Chapter 5) that existed in comparison to the mainland areas. Contact via boats

in all directions, except directly east, would have been difficult due to the prevailing marine

conditions. Trade and cultural ties to the south would have been heavily dependent on

tidal and weather conditions. It is extremely probable that the occupants of the

Doggerbank would have regarded such contact as 'risky'. These links may have been a

method of gaining prestige items rather than serving a utilitarian purpose. This is a possible

explanation for the presence of Michelsburg axes on these islands during the end of their existence (Gaffney *et al.* 2009, 145). Although of a significantly larger distance, similar trade links across the North Sea to Northumbria would have been possible with similar caveats. Direct cultural contact to the east with Denmark, would have been possible, but we must consider that all the rivers in this region flow south. If we consider the archaeological supposition that rivers formed the route ways of travel to be correct, then it is difficult to see how contact over land would have occurred. This, however, is not a major issue as the area would have been inundated fairly rapidly after the inundation of Outer Silver Pit.

This being true, it would have been possible for irregular contact to have occurred by following the coastline, where currents were moderate in strength. The possibility of contact with both Denmark and northern England must lead us to expect that the populations in zone 3 could share similar cultural elements to the populations of these regions. Waddington (2007: 220 to 221) suggests that the introduction and adoption of narrow blade technology would have followed this route. If this is correct, it suggests that narrow blade technology originated from the North Sea, and specifically the Outer Silver Pit area. Further, if Waddington's (2007:220) observations on the similarities of technological elements between Denmark and Britain are also correct, then we should expect the populations of zone 3 to possess a more comprehensive mix. The time period indicated for the similarities suggested by Waddington (2007) fit the date at which the situation illustrated in Figure 6.6 occurred.

As no reliable, *in situ* archaeological material is available within this area for this archaeological period, the argument must remain, for the present, as supposition. However, it does provide archaeology with a testable hypothesis should such material ever be located. Whilst the difference of the groups in zone 3 is presently untestable, it is possible to consider the relationship between zones 1 and 2. Taking the landscape boundaries into consideration, can anything be discerned from a comparison of the existing two regions? Whilst most scholars suggest that a distinct boundary exists once the area is fully inundated (Jacobi 1976), few consider the possibility that boundary conditions could exist within the landscape between the British and European Mesolithic records prior to the submergence of the landscape (Clark 1975).

Characteristic elements of the British cultures, such as the Star Carr type trapezoids, can clearly be seen to be absent in contemporary continental cultures (Reyneir 2005), whilst proposed links to the Deepcar type, which were used by Clark (1975) to suggest cultural links across the North Sea basin, have been challenged by recent work (Reyneir 2005 citing Verhart pers. comm.). Indeed, the majority of contemporary evidence suggests that no exact parallels to British types can be found on the continent. Whilst this could be due to the distances between the material, the presence of physical barriers within the landscape would further strengthen this situation. Landscape boundaries, such as rivers, can serve as boundaries to ethnographic groups (Silberbauer 1996), and it is likely that a similar delimitation occurred in the Mesolithic (Spikens 2008). This would not necessarily have precluded contact for trade and religious purposes, rather the presence of such landscape obstacles would have made regular, easy contact between groups from zones 1 and 2 more

difficult. Such a process would reinforce group identity, as well as serving to reinforce a

feeling of otherness.

Irrespective of the terrestrial conditions between zones 1 and 2, maritime trade between

the two areas would have been possible. The currents located in the Outer Silver Pit, whilst

serving to prevent travel directly across the estuary, could, with knowledge of the tidal

conditions, be utilised to facilitate travel. Exploitation of the prevailing currents, if timed

correctly, could be utilised to enhance travel to allow rapid trading voyages from areas such

as southern Northumbria to the edges of zone 2. The need for landmarks during marine

travel is essential under these conditions. In more recent times, churches appear to have

been positioned to aid pilotage (Binns, 1980). Mesolithic communities navigating within

this area would not have had such advantages; however, the relics of the inundation of the

past landscape may have provided important navigational markers. Tidally exposed

submerged forests and palaeochannels would have provided valuable waypoints within the

landscape. Waddington (2007:205) observes that the North Sea, if observed within this

light, would have provided a valuable means by which goods could be traded. This would

have extended the economic sphere and generated reciprocal relationships between

Mesolithic groups. If there were taboos about landing on such sites, either to rest or to

escape the tide, we will never know. However, we do know that Mesolithic people did

work and hunt in similar environments (Bell 2007), and so the ancestors cannot have had a

too formidable aspect. Yet, for the groups who would have travelled through such a dead

landscape, the act of acquisition items of rarity would have been the primary focus, and

prestige must have also been gained through the very act of travel through the lands of the ancestors and the stories told subsequently by the traveller.

6.4   Discussion: Inundation and its effects - The beginning of Britain

The submergence of this region would have had other more immediate effects upon the occupants of the region, namely the possibility of migration within the region. At a small scale, the loss of a village during the Mesolithic, perhaps precipitated by a storm breaching a sand bar, would have had immediate consequences. Although inconvenient, this would have represented only a small risk to mobile hunter-gathers. Lost tools and houses could be remade, whilst lost foodstuffs could be replaced from resources in the surrounding landscape. Thus, the overall impact would, therefore, have been much less than one might expect. However, the large scale loss of extensive tracts of lower lying land would have exerted pressure upon Mesolithic peoples to move to new territories. Waddington (2007:205) contends that the production of the large structure at Howick was a direct consequence of this pressure and the need to delimitate ownership of the landscape to groups competing for space.

This evidence for pressure derived from marine inundation, although currently unavailable for the Doggerbank, can be demonstrated from other areas. The evidence for violence from Skateholm (Mithen 2003: 174-5), although from a slightly later period, is of particular relevance. Indeed, there is a growing awareness that violence may have been endemic amongst communities experiencing such pressure. Mithen (2003), for example, notes

southern Sweden was already losing large areas of its coastal strip to rising sea levels during the period when Skateholm was in use. The tension between competing communities under pressure from landscape loss must have been significant, and is perhaps reflected in the number of injuries to the dead including head wounds and arrows embedded in the bodies (Midgley 2005, Spikens 2008).

The results of this thesis are significant in light of such evidence. The results as presented in Chapter 5 show quite clearly a rapid loss in population potential after 9,000BP (Figure 5.36). Although the qualitative model is unable to produce absolute figures for this loss, the ratios are large. The figures suggest a 63% loss in population potential between 9,000BP and 8,500BP (Table 5.5), and an 86% loss in population density (Table 5.6) for the same period. Such a figure represents a huge change in the population potential for this area. If, for example, an optimal environment figure of 0.1 persons per km^2 (Smith 1992) is utilised over the entire study area, then a population of 332 people would be expected within the thesis study area at 9,000BP. If the losses stated above are applied then only 123 people would remain by 8,500BP. If we consider the figures for 9,000BP, assuming no population change due to mortality, this would suggest that 209 people would have been displaced over a 500 year period. Whilst this may not seem like a large figure, in terms of a hunter gather society, these figures would have been as large as ethnographically reported tribe sizes for Australia (Birdsell 1968, 229). Even considering an average ethnographic band size of 25 (Lee and Devore 1968, 11), the figure represents at least 8 major groups. Such large volumes of displaced persons moving into the surrounding areas of Britain and Europe could well generate the pressures suggested by the archaeological record.

274

The requirement to emphasise ownership of the land and its resources would have become increasingly urgent as more people were displaced by the emerging North Sea. If we scale the figures up from the 4,500km^2 of this study area to consider just the area of the emergent landscape covered by marine 3D geophysics (46,000km^2, see Figure 1.1), the 63% loss figure for 8,500BP reveals a displaced population of some 2,898 persons. When we compare this to the likely population numbers for the north of Europe at this time period (thought to be in the tens of thousands: Smith 1992), this figure is very large. Indeed, as this only represents approximately half of the emergent landscape at that time, the actual figure is likely to have been much larger.

Given the increasing availability of marine resources in the region, it is perhaps no wonder that structures such as Howick appear in the landscape at about the time of this potential population displacement (8,715BP +/- 45, OxA-11831, Waddington 2007). As the results show, the resources available from marine sources provide an incentive to reduced movement in the landscape, and the need to protect such resources from a migrant population may have been a real requirement. One of the main questions raised by Waddington (2007) was the question of why Mesolithic house structures seem to disappear from the archaeological record some 500 years or so after they appeared. This question may have a simple solution, linked to the reduced displaced population numbers after the initial event at 8,500BP. If we examine just the results from the thesis study area, we can see that after the initial displacement of 209 people between 9,000 and 8,500BP, this displacement stops in the next 500 year period. If we consider this in simple terms, the

period 9,000BP to 8,500BP sees a population migration of 0.4 persons per year, while the period 8,500BP to 8,000BP sees increased resources, and therefore no population loss. It is quite apparent from these figures that the impact of migration during these two 500 year periods would have been significantly different.

Perhaps what the creation of house structures during this period tells us, is the scale at which Mesolithic society responded to change. If the modelled figures identify a real effect, then it suggests that the response to change is relatively rapid. Therefore, the migration levels provided by the model give, for the first time, a quantification of the level at which Mesolithic populations responded to migration. The creation of structures such as Howick required a major and sustained effort to create (Waddington 2007) and the occupants of the structure obviously felt that this was required. Conversely, after 500 years of house building something had changed, and the response was to discontinue house building. The model suggests this is a response to a decrease in migration. Indeed, increasing marine resources during the preceding period suggest that the new convoluted coastlines' marine resources acted as a buffer, slowing the impacts of landscape loss on resource availability.

If the model is examined more closely, there is a later loss in population potential of 83% during the period of 8,000BP to 7,500BP. The question occurs; Why is there not another return to house building? The answer is provided by the model. The qualitative model suggests that the resources supporting the population during this period kept the potential population at a relatively low level. Thus, even though the losses in relation to the study area population are relatively large, because of the lower maximum supportable

population, the potential for migration is significantly smaller than that occurring between 9,500BP and 9,000BP. It is therefore likely, given these lower numbers, that conditions did not require a return to the tradition of house building.

If this is applied at a greater scale across Doggerland, then the pressures on the surrounding population must have decreased. Whilst Waddington (2007) observes that pressure is less when Britain is finally isolated from the Continent, the results of this thesis suggest that the increase in coastline may have provisioned sufficient resources to reduce the pressure before this separation occurred. Significant proportions of the landscape would have continued to be flooded after this date, and the pressure must have continued, but at lower levels. However, the scale may have been much less than the initial loss at 8,500BP. The effective need for delimitation of territories remained, but the lower numbers of displaced persons suggest that less permanent structures would have been required, and hence is a possible explanation for the end of construction of houses such as Howick.

It is interesting to consider the effects on other nearby areas. The later push observed in the model corresponds in part to the evidence for violence observed in Denmark (Midgley 2005). If this migration is linked to this emergence of violence, then this suggests a difference between the responses to pressure. Perhaps the cultural differences between migrants were too great, or there was already pressure on resources, and Denmark was "full" in Mesolithic terms. Either way, even though the numbers of people involved would have been lower, a response is observed. Why a similar response does not occur in the British archaeological record should be considered. The options suggest that our current

lack of major cemeteries in the North East of England may be the main reason we are not observing such phenomena (Conneller 2006). There are other potential possibilities; social relations may have reduced the incidents of violence, or the lower levels of migration into the area may not have been sufficient to provoke violence.

Oronsay, a small island surrounded by other islands, and a mainland some 20km away, holds some interesting parallels to events in the southern North Sea. During submergence, the landscape would have fragmented into islands (see Coles 2000). As Mellars (2004) hypothesised for Oronsay, marriage links between islands, and indeed the continental area, must have been important to maintain genetic viability. Indeed as Smith (1992: 12) illustrates this must be occuring over a wide area. The implications of this for the southern North Sea in the Later Mesolithic period are significant, as the marriage patterns would have not only included other islands in the area, but would also be linked to Britain and the continent. Bang-Andersen (2003: 11) observes that these areas would have been visible from the continent on clear days, and Coles (1998: 75) does not rule out social contacts in this period.

This "chain" of relationships would have facilitated trade, and would have produced alliances and social networks (Mithen 1999: 16), which would facilitate the movement and integration of the population of the North Sea into other areas as the landscape shrank. The process of assimilation assumed by Coles (2000: 54) perhaps requires modification. The areas in which the inhabitants of the remnants of North Sea plain would have sought to move into would not have been purely inhabited by "inlanders"(Coles 2000: 54), but

probably people with a similar background in exploiting marine resources, and possibly even descendants of earlier colonists from the southern North Sea (e.g. Bjerk 1995). This differs from Coles (2000), who considers that the displaced inhabitants would have utilised their better coastal adaptation to displace the existing inhabitants of the continental landscape. This, however, ignores the common ancestry that both groups would have possessed (Bang-Andersen 2003) which may have facilitated their integration. Additionally, the ongoing marine inundation would have continued to generate a diverse coastline, which would have been able to soak up some of this population. The overall result would have been an increase in population and archaeological visibility, which would required an increase and diversification in the resource base utilised. This suggestion is intriguing, as several scholars observe an increase in the utilisation of resources for the Later Mesolithic (Jochim 1998, 210, Morrison 1980, 136).

Given these conclusions, and the presumed significance of the Outer Silver Pit to Mesolithic communities in North Western Europe, the inundation of the area would have driven social change that rippled outwards from this region as the landscape continued to be inundated. It can be argued that this may have been a turbulent time socially, and potentially the tipping point for the Mesolithic psyche. Once culturally united by this landscape, the inhabitants may now have perceived it as a frontier. As observed previously, the nature of the landscape has shaped and moulded the character of the Mesolithic in this region, and this is reflected by the data presented here. In conclusion, therefore, the impact of the landscape of the southern North Sea and its loss is fundamental upon the development of the Mesolithic of Northern Europe.

6.5   Discussion: The archaeological record and its applicability offshore

A question raised by this thesis is the issue of the current archaeological record and its applicability to the study area. The primary reason for this is to ask whether there is already enough evidence to understand the Mesolithic of this region. Given the cost of research in marine areas and the issues of prospecting for sites on land, why waste research money looking in the marine sphere where we are much less likely to find direct evidence ? The answer provided by the results of this thesis suggests that there is a whole range of unknowns that require further research. Indeed, the possibility of cultural difference suggests that the present archaeological record may not be totally valid in this region. Whilst sites like Howick, and the evidence for violence, tells archaeology something about the tensions of the period, they still may not tell us much about the actual populations of this landscape. Waddington's (2007) theory of the migration of populations from the North Sea landscape may suggest that elements of the current archaeological record may have resonance to earlier populations of the area. However, it does not tell us what happens before this of migration. The model suggests that the conditions for the generation of sedentary behaviour were present before the onset of this migration; however it appears that it is a reduction in resources, and hence supportable population, within the North Sea which drives the building of houses. In truth, however, the only solution to the issues raised by this thesis is the provision of more information through marine survey.

In such a situation, individual sites from the current terrestrial zone may provide us with an overall landscape picture that is shadowy, but the application of this knowledge across the

whole of the temporal and spatial area of the southern North Sea is difficult.

Archaeological approaches which move away from the sites to the landscape offer a way

forward (Young 2000), yet there still remains a fundamental absence of archaeological data

over much of the Mesolithic landscape. The absence of *in-situ* finds has long made the

North Sea emergent landscape appear an unattractive problem to archaeologists. It is

interesting to observe that when finds are plentiful, such as in offshore Denmark,

archaeologists are more than happy to consider this information (e.g. Verhart 2004, Fischer

2004), but usually to support their terrestrially derived viewpoint (David 2006).

Such a terrestrial centric viewpoint can be observed in the isotopic analysis from human

remains from the North Sea area. For example, a skull fragment from the North Sea, dated

to 9,640BP (UtC 3750, Erdbrink and Tacoma 1997) produced a terrestrial response with

respect to the isotopic component related to food resources. This may appear

contradictory to the casual observer, since the North Sea region is thought to include the

past coastlines. Indeed, Barton and Roberts use this in their argument against the

utilisation of marine resources in the Early Mesolithic (2004: 348). This, however, illustrates

some of the issues in utilising the present terrestrial knowledge to fill in the missing areas of

offshore knowledge. In this case, it is important to consider the location of this find, which

was recovered in a near shore area between Britain and the Netherlands. At the time the

person was alive, the area was very far from the palaeocoastlines of that region. Given the

lack of available reliable mapping (before Gaffney *et al.* 2007) this mistake is, perhaps,

understandable, however, the speculative maps of Coles (1998) were available. This

example highlights the issues well. It is often hard to understand the fact that the marine

archaeology of submerged landscapes actually represents a different type of terrestrial record. Indeed, Pryor's (2004) discussion of his difficulty at understanding the problem during the early years of his career represents an honest and admirable recognition of this.

Conventionally, the Early Mesolithic has been seen as period where populations moved between the coastline and the interior (Clark 1954, Fischer *et al.* 2004). In the case of Clark, this was postulated on the existence of amber beads, or later through the relationships of sites to areas near palaeocoastlines or rivers (Barton *et al.* 1995, Fischer *et al.* 2004). This can be seen in the Star Carr model, published in 1972 by Clark. This model has been frequently adapted, even being utilised by Spikens (1996) within computer simulations. The model assumes a summer base camp in the uplands, whilst moving to a winter camp on the coast. The significance of the coastal zone, and a possible relationship with the interior of modern England, has been observed for some time, descending ultimately from Clarke's informed recognition of this area in his model (1960s). This has been modified in various formats as a series of difference movements (Rowley-Conwy 1995), location of occupation (Simmons 1996), and season of occupation (Lovis *et al.* 2006). However, the movements through the landscape are linear (see Figures 6.8 and 6.9), and are supposed to follow red deer migrations.
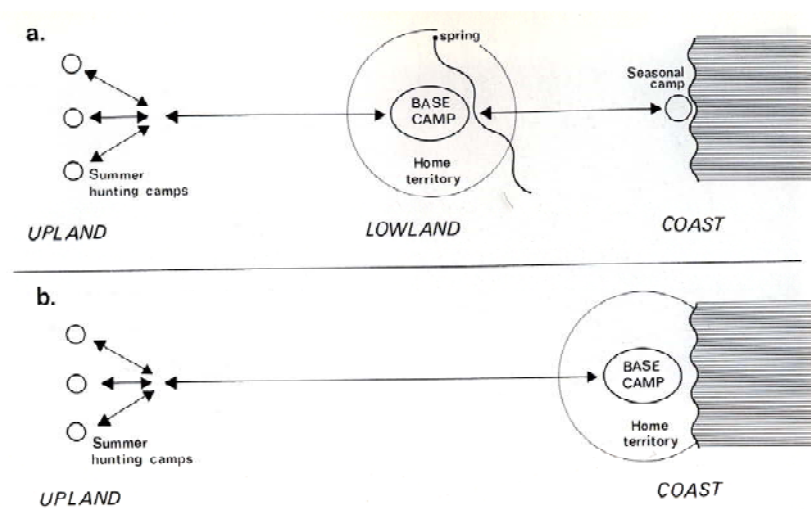
Figure 6.8 Clark's 1954 model of population movement, based upon his research at Star Carr.
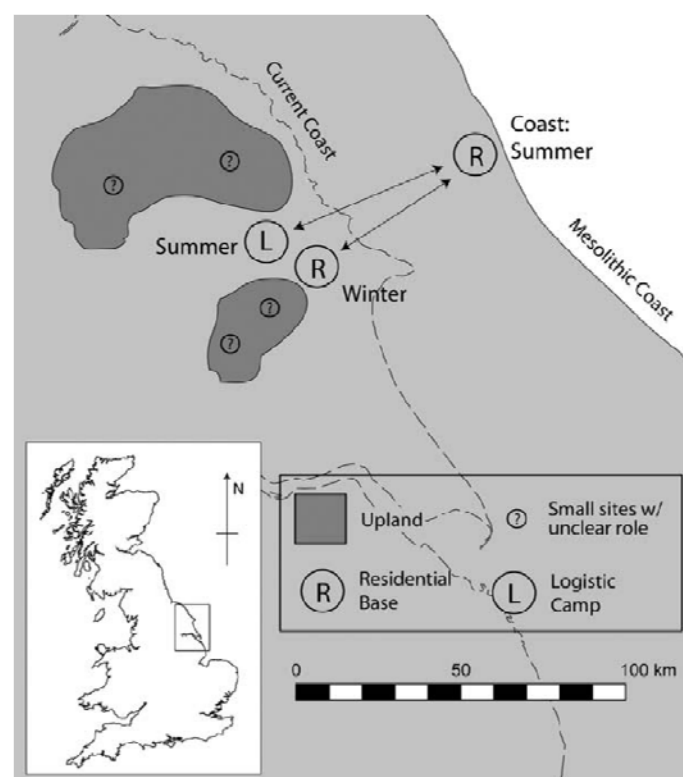
Figure 6.9 Rowley-Conwy's 1995 revision of the Star Carr model.

Some archaeologists question the validity of seasonal movements, especially in communities near the coastal zone (Carlsson *et al.* 1999: 65, Karsten and Knarrstrom 2003: 212, Waddington 2007). Reynier (2000) observes a series of other reasons why such ideas are far from perfect. These criticisms have also been made by Carlsson *et al.* (1999:65), who observes that the sites used within the Star Carr model, and later versions (Rowley-Conwy 1987) are limited and unrepresentative. It is important to note that the evidence of coastal visitation utilised by Clark to support this model could well be gained through trading activities with cultures that were located on the coastline. The possibility of trading networks is supported by Schulting and Wysocki (2002), who highlighted the occurrence of winkle shells in the Aveline's Hole cemetery in a wholly terrestrially based community. This illustration shows that there is scope for development of models of mobility and social contact, especially when considering the southern North Sea.

The possibility of a coastal culture and its trading links are not considered in the Star Carr model. This is, in part, due to the lack of early Mesolithic coastal material (Milner 2006: 68), yet, in places where this does exist, the diversity of resources suggests that fixed coastal territories can occur (Nordqvist 1995). This sedentary behaviour has relevance to the North Sea plains since it is fundamentally different from the models derived from purely terrestrial evidence. Indeed, whilst many of these models acknowledge the existence of coastal resources and their attractive nature for occupation (Clark 1954, Spikens 1996), they have ignored the evidence that year-round resources were available from the coastline, and that maritime resource utilisation was favoured (Indrelid 1978, 169-70, Nygaard 1990, 232). There is then the possibility of mutually exclusive resource systems

that may have existed in the early Mesolithic of the North Sea (Norqvist 1995, Barton and Roberts 2004). The presence of structures and burials at this time along the coastline suggest some sense of land ownership which could have denied access to coastal resources (Verjux 2003: 267).

Indeed, it is exactly Carlsson's argument (1999) on the representativeness of sites and models, which is so important in respect to the marine zone. As we do not have any actual sites for the southern North Sea, it is debatable whether the ones presently on land are truly representative. As the results presented here have shown, the resources, population pressures, and possibly even culture, would have been fundamentally different to those on the present terrestrial land mass. Therefore, can we truly expect Mesolithic sites from the Doggerbank to be properly represented by cultures situated some several hundred kilometres away? The answer to this question, and indeed this section, is ultimately that it is probably not representative. But, without absolute data from this region we cannot, as yet, escape this issue. Indeed, with the absence of material from this area, it is the only through the use of terrestrial material that we are able to inform our archaeological consideration of this area.

6.6   Synthesis

As this chapter has discussed, the models constructed herein have provided data of archaeological importance which allows us to better understand the Mesolithic of north west Europe. As discussed previously in this section, it is proposed that the centre of the north western European Mesolithic is likely to be centred in this region, and its significance can be highlighted by the surrounding archaeological material (David 2006). The insights have suggested the significance of the Outer Silver Pit, together with possible cultural implications and solutions to the issue of Mesolithic house disappearance; these represent a major improvement of our understanding of the Mesolithic and its relationship to the surrounding landscape, and an achievement of **objective 3.4** and **Aim 3** of this thesis.

Yet, as observed in the final section of this chapter, and indeed Chapters 1 and 2, the present archaeological record is far from complete. This situation may suggest that the results of this thesis may well be far from representative, due to the incomplete nature of the data. The study only represents some $4,500km^2$ of landscape from a possible $62,000km^2$, less than 13% of the total landscape. Additionally, the model is limited in its temporal scope by its use of Holocene environmental data. Yet, if we examine the results provided in Appendix 3, it is apparent that similar landscapes and features exist across the whole of the southern North Sea. Therefore, the results presented by the model can be used more broadly, facilitating an understanding of the data from a local to area based scale. This is a better situation than that presented by the terrestrial datasets, which form only a rim around the southern North Sea (Chapter 2). Conneller and Warren's (2006)

preface to "Mesolithic Britain and Ireland : New Approaches" states "The British and Irish evidence represents the real material conditions of Mesolithic Life" (Conneller and Warren 2006: 10). The results of this thesis clearly show that this is not entirely the case. Whilst the current archaeological evidence represents the conditions occurring during the Mesolithic on the current terrestrial British landmass, the conditions in the North Sea landscape, of which Britain was only part, were somewhat different.

Indeed, as argued in this chapter, these may have been sufficient to generate major differences between the groups located in this area. The increasing maritime resource base is shown by the model to provide the conditions to produce two separate groupings, and valuable confirmation can be seen in groups thought to originate from these peoples (Bang-Andersen 2003). This situation offers a new insight into the terminal stages of the southern North Sea landscape. Previous scholars, upon consideration of this problem, have considered the region to have divided into two distinct groups by inundation (e.g. Jacobi 1976). Yet, this position ignores the presence of a third, distinct landmass during this period, Doggerland. The increasing separation of the Doggerbank and mainland Britain and Europe would have served to increase this social difference. As this chapter has suggested, this, in combination with environmental and subsistence differences, must have generated a sense of "otherness" to those peoples located in Britain and Europe.

If we feed this information back into our debate about the representativeness of the terrestrial record, it is apparent that this area is missing from the interpretation. But, as we do not have any evidence from this area, it is impossible to include it within an

interpretation based solely on artefacts. In fact, the terrestrial bias of the data used to

interpret the Doggerbank island (Chapter 2), has caused this area to be ignored, with only

Coles (1999) noting the significance of the area. The results of the model, however,

overcome this issue and emphasise the importance of this area. Thus highlighting the need

for caution when projecting, into the marine zone, an interpretation based on terrestrial

information. This new insight offers fresh perspectives on the effects of inundation. The

results of the thesis show that inundation may well have provided the impetus for

Mesolithic house building and driven an upsurge in violence. Whilst this may have been

suspected by some authors (e.g. Waddington 2007), the model provides information on the

possible mechanisms which drove this change and the scales of their operation. Yet, the

model goes further, in offering an insight into the positive impacts of this inundation. The

model clearly shows the beneficial influence of the presence of marine resources, and the

potential it had in increasing the subsistence resources available to the population. This

provided a positive buffer to migration after 8,500BP, reducing the effects of the main

migration to only the timescale between 9,000BP and 8,500BP. In providing such results,

the model succeeds in its goal, offering new information, and assessing the validity of the

older terrestrial views on the southern North Sea region.

As discussed above, the results have importance through the understanding provided. This

transcends the findings that could be revealed for one site or for a collection of finds. It is

through consideration of the spatial and temporal changes caused by the evolution of this

landscape, that it becomes possible to truly understand the place of the southern North Sea

within the Mesolithic. The region is not, as previously thought, a "landbridge" (Jacobi 1976)

or a blank canvas, but a significant region whose loss impacted upon the development of

the Mesolithic overall (Coles 1998). Whilst the qualitative model produced by this research

does not produce absolute figures for this occurrence, it does allow significant events to be

placed in their temporal and spatial context. This facilitates their consideration within the

current archaeological record, and hence, the application of the models results within

regional interpretative regimes.

CHAPTER 7

CONCLUSIONS

7.1   Introduction

This thesis has explored the challenges of studying the palaeolandscape of the southern North Sea. In particular it has focused on the relationships between environmental change, available economic resources and the possible human population that could have been supported at different times and in different locations within the study area. In order to address these challenges, a modelling approach was used to firstly reconstruct the past landscape (and changes to it through time), to investigate the resource carrying capacity of this changing landscape, and to explore the potential for human populations living within it.

The resulting model provides the ability to allow research into the impacts of marine inundation upon the potential human occupation of the study area during the Mesolithic and has led to the generation to new hypotheses relating to human-landscape interactions. Furthermore, this research has facilitated the exploration of questions relating to cultural identity, settlement patterns, conflict and permanence of occupation (such as houses).

Similarly, this study has highlighted how modelling techniques can create hypotheses for exploring some of the cultural interpretations identified from other sources of investigation, such as the patterns in the material culture record, or the pattern and timing of house construction. This research is significant as the hypothesis produced provides new

information, new avenues for research and a new insight into the Mesolithic of this area, the ability to test this information is highly significant. The new perspectives gained through this research now offer a fundamentally new position through which the archaeology of the region can be considered and understood.

The significance of this research therefore extends beyond the remits of the specific study area. The models generated have applicability within other areas of similar inundation both spatially and temporally, and these global implications will be explored further in this chapter (7.5). This is an important achievement, especially in light of the realisation that many aspects of early prehistoric settlement are not truly comprehensible without an adequate understanding of these previously unexplored regions (Bailey et al. 2004). The power of the model to provision new information for these marine areas offers the potential therefore to significantly advance our understanding of world prehistory.

During the course of this thesis, the difficulties of research in the marine zone have been considered. A primary cause of this difficulty is the need to generate significant amounts of base data and apply appropriate base mapping. Coles (1998), for example, observed that the mapping for this region had evolved little since the time of Grahame Clark. As such, it is perhaps not surprising that the archaeological knowledge of this area had been little further advanced from the 1930s (Coles 1998). The need for a different approach to research, given these issues, is obvious (Chapter 2). Thus a methodological approach to meet this demand for information was formulated. The generation of datasets has been a major task (Chapters 3 and 4). Unlike the situation on land, even the simplest datasets were not

available "off the peg". This requirement led to the utilisation of 3D seismic data to provide

the required datasets. This has resulted in the development of new mapping techniques

which have now fed into further landscape mapping programs around the world (see legacy

section below for further discussion). The utilisation of geological 3D seismic data within

this thesis to provide the required data is a solution to Cole's (1998) identification of the

need for spatial mapping at an appropriate resolution. Given this situation, even the base

data layers of this thesis have therefore generated new and novel information (Chapter 5).

In addition to the base data, it is also important to appreciate the importance of the

model's results. The combination of qualitative and predictive modelling in this thesis

provides new insights and a development of knowledge for this area. It is important to

stress that the model results do not represent absolute or real values; rather it is the ratios

and proportional changes observed that are important. In this light the qualitative model

achieves this goal, through the provision of a scenario within which we can consider and

understand the surviving Mesolithic record.

The main strength of the model is that the results have produced a series of testable

hypothesis (Chapter 6). Whilst some of these may only be answered in the long term owing

to the requirement for information from areas of difficult archaeological recovery and

research, it does provide a valuable framework within which we can place chance finds and

material recovered by development. The hypothesis of three groupings across the North

Sea plain, for example, could be tested by the recovery of cultural material from these

areas. Whilst recovery would be a difficult proposition, the predicted sites, provided by the

analysis, offer the potential to effectively search for this material. Given the relative

restrictions of archaeological budgets; it may be some time before such material is

recovered. Ongoing development within this region, however, potentially offers a route

through which such investigations could be undertaken. However, the model does suggest

another route via which the hypothesis could be tested. The environmental changes which

are present in the model would have caused change that would be observable within coring

material taken from this area. A full archaeoenvironmental sampling program could

indicate whether the environmental conditions predicted in this hypothesis occur in reality.

Such an undertaking is well within the scope of current archaeological sampling

methodologies (Pletts *et al.* 2007 is an example of such work).

The model has produced a hypothesis that predicts the nature of the population push

resulting from the submergence of the landscape, and its effects on Mesolithic peoples.

Again validation may well be achieved through a utilisation of new environmental material.

This may also be possible through an examination of the available cultural material from

both the North Sea and surrounding environs. By adopting the "inwards out" approach to

this situation, suggested by this thesis (Chapter 2), such an undertaking may be realistic in

the near future. This could be achieved through the examination of the rates of change of

both the sea level and the environment in correspondence to the available archaeological

evidence. Since the hypothesis generated by the model suggests date ranges and scales of

effect, it provides a series of targets within the records which could be the focus of further

research.

A summary of results will now be provided in this concluding chapter. Following this, a discussion of the approach undertaken and possible future improvements will be provided. The chapter will then consider the research legacy of this thesis. Finally, the chapter will conclude with a consideration of the results in a wider perspective and their possible implications worldwide.

7.2   Summary of results

7.2.1 Base data result summary (Aim 1)

The results of the generation of base data saw the application of the interpretative values from the 3D seismic information. From this initial data layer, a variety of landscape features were identified. Features identified included rivers, lakes, coastlines and marine zones **(Objective 1.2)**. From the examination of the seismic data it was apparent that the seismic image could be interpreted in a similar manner to an aerial photograph. These results provided a base GIS layer with which to populate the topographic layer. Additional topographic information was also derived from the seismic records **(Objective 1.1)**. This provided the structure of the landscape on which the modelling could be performed. It must be noted that the landscape layers generated by this exercise provided considerable improvements in detail compared to the bathymetric data for the region.

Investigation of fluvial channels revealed that their morphology was comparable to existing fluvial systems of today. Three different types of system were recognised: The first low sinuosity group fell into the stream type "D" (Rosgen 1994) and therefore falls into the classification of braided systems; the second group of intermediate sinuosity fell into the

"DA" category of anastomosed systems. The final category of highly sinuous rivers fell into the "C" category, as meandering systems. This grouping was mirrored by the analysis of sinuosity following the classification system developed by Leopold *et al.* (1964). These figures all fell well within the bounds of modern systems.

A soil data layer was generated from the available geological mapping and seismic information **(Objective 1.3)**. It must be observed that whilst this is the first known attempt at the production of this data layer for the region, it was successful in generating a usable soils map. As the predominant parent material in the region was glacial boulder clay, so the most common soil was a wet basic soil. There was considerable homogeneity of the soil types across the region. However, given the wide distribution and common nature of the parent material this was not surprising.

The tree succession maps **(Objective 1.4)** provided one of the first surprising results of this thesis. The maps suggested that 8,500BP was an important period. During 8,500BP a major change can be seen in the woodland, with birch being replaced by elm and oak as the main woodland types. What was significant was that the results showed that this change is reflected in the actual physical landscape when a sea level curve was applied **(Objective 1.5)**. The north of the study area, on the Doggerbank, can be seen to be elm dominated woodland. However, the southern part of the study area, and a small island on the flanks of the Outer Silver Pit, can both be clearly seen to be oak-dominated. This separation is most reasonable, since the area separating these two regions is submerged. Whilst the effects of this submergence as a barrier to oak spreading were speculated on, it

was noted that insufficient data was available to consider this further. It was noted that if this situation was reflected in reality it would affect the resource distribution between the two areas.

7.2.2 Qualitative model result summary

The qualitative model results presented the modelled resource yields for the areas **(Objectives 2.1, 2.2 and 3.1, 3.2)**. The results for Boreal conditions revealed a major difference to previous qualitative models. This was achieved through the inclusion of marine resources which generated important differences in the yields. There were major increases for resource usage for grey seal during September, and common seal in July. The Atlantic conditions presented much changed conditions; whilst a large number of grey seals apparently are still being caught in September; high values for red deer and wild boar prevail throughout the year. Such a result would suggest that for the later stages of the study, the use of the coastal zone would be predominantly an autumnal activity. The models support values were then also provided. These were given as maxima values, which it must be stressed are not literal values. It was observed that the controlling period of support was winter for all time periods, and thus it was this value that was focused upon. The results were then presented by temporal period, starting at 10,000BP and ending at 7,500BP with the submergence of the area.

In terms of overall resources, the environmental shift from Boreal to Atlantic conditions in the model produces a minor increase in the level of support possible. This is achieved with the backdrop of a rapidly diminishing landscape. Perhaps of most significance, is the impact

of marine resources upon the modelled population support levels. Values of between 2.5

and 3 times the levels of the terrestrial and lacustrine resources are observed for the

marine area. This is even more pronounced in estuarine areas, and perhaps serves to

highlight the importance of the diversity of resources within these areas. This effect clearly

demonstrates that marine inundation could have affected human subsistence. It was

apparent that the modelled results show that whilst marine inundation represents a loss of

landscape, it did not necessarily mean a loss in resources. The relatively modest area of

inundation that was seen for 9,500BP was more than offset by the increase in resources

associated with the marine inlet. It is, perhaps, only later, when the rate of landscape

inundation increases and a greater proportion of the study area is inundated, that the

overall population supportable by the resources started to decrease.

As the habitable land decreases drops some 90%, from just under 4,500 km^2 at 10,000BP to

only 500km^2 at 7,500BP, the population supportable can clearly be seen to decrease. Yet,

this is not a linear relationship as several major deviations can be seen in the results; with

the decrease in maxima values representing a 78% decrease in modelled population. This

result shows that whilst initially there is a potential population gain, the overall trend is a

reduction in population potential due to landscape loss. Whilst the scale of occupation can

therefore be seen to change in relation to landscape change, the relationship to population

potential is a complex one. This lack of proportionality between sea level rise and

population maxima values is due to the presence of marine resources and their surface to

area ratio. At the start of the inundation the amount of coastline is relatively small and

unconvoluted in relation to the large terrestrial area. However, this falls as the length of

297

coastline increases in both length and convolution. This reflects the increasing complexity of shoreline produced as inundation proceeds. Since the marine coastline is able to support up to 3 times that of the terrestrial zone, the loss of landscape in relation to population is therefore partially buffered.

The effect on the modelled human population was observed through the monitoring of the maxima population density in relation to the sub-aerial landmass through time. At 10,000BP the average maximum population density (based on the modelled economic resource) is around 8 per square kilometre. This increases to a value of 15 at 9,000BP and this is a direct result of the availability of marine resources within the model. However, the loss of landscape during 8,500BP serves to depress the density to around 7.9 per square kilometre. The increasing proximity of marine resources relative to the small amount of land available, and the effect of the surface to volume ratio observed above, can be seen in the results after 8,000BP where the maxima population densities rise dramatically to over 17 per square kilometre. Whilst these are maxima population densities, and therefore do not represent true population density, the increased population potential density ratios indicate the possibility of a change in the level of occupation and thus have significance.

Even given the relatively low population numbers estimated for the Mesolithic, such a rise in population potential density would have real and significant effects. The population potential increases from 10,000BP to 9,000BP by approximately 25% and is large enough to be considered significant. Similarly there is increase in population density from 8,000BP to 7,500BP of approximately 20%. However, given the lower modelled population at this time,

this rise is thought to have had a lesser impact than the earlier period. Conversely, there are significant falls in the population potential and its density. The 9,000BP to 8,500BP interval marks a dramatic drop in maxima population supported by the available resources. This is also reflected in the population density, which is very nearly halved during that period. The results presented, suggest that while this is partly buffered in the coastal zones, the change is so significant that the effects are distributed over the whole of the study area.

7.2.3 Predictive model result summary

The first stage was the generation of a predictive model for site location **(Objective 2.3)**. The simplistic nature of the model and the use of purely environmental data does not allow for a prediction of site type or site size. It was the very nature of the model to predict an area of likelihood over an area of a few tens of meters rather than to provide an absolute location.

The model clearly suggests a preference for settlement in coastal locations, and specifically areas of fluvial/coastal interaction. This is perhaps to be expected given the weightings within the model. It is perhaps a limitation of this model that it preferentially predicts for site location in coastal areas. Whilst this initially may not seem a major issue, since preferential settlement is widely believed to have occurred in these areas, the very high coastal values effectively mask areas of interest occurring in areas further inland which may have equal archaeological validity and value. One possible solution to this issue, if more time was available, would be a second iteration with the coastal element of the model

removed. Thus, a combination of both iterations would facilitate a more balanced

prediction of possible archaeological site location.

The predictive model has shown that it is possible to apply the principles of predictive

modelling to submerged areas of the southern North Sea, where the data is of sufficient

quality and density. Although it was not possible to model the entire study area, the

resultant model generated by this thesis has shown its ability to predict sites in a range of

landscape environments throughout the temporal and spatial changes under examination.

7.2.4 Catchment analysis result summary

The use of catchment analysis proved beneficial, since it allowed for a consideration of

factors that was not possible within the simpler predictive model. The methodology used in

this thesis (Chapter 4) considered the use of catchment analysis as a way of combining both

the results of the qualitative model and the predictive model **(Objective 2.4 and 3.3)**. This

was achieved by utilising the location of the resulting predicted area as the nodes from

which catchments could be calculated. These were then overlain onto the qualitative

resource map to produce a resource forecast for each predicted site.

The results clearly show that the overall population potential density record within any

given catchment is reasonably independent of catchment area size. This situation is true

for all the time periods studied, with the majority of the anomalous values being caused by

surface to area effects within the data. Average catchments were generated for each

period to gain a better understanding of the overall trends. This revealed that the 9,000BP

result appears to represent a sharp reduction in terms of population potential and density, and thus is a point of major change in the more local scale and level of occupation within the landscape.

When the average catchment size was examined (Figure 5.56), it became apparent that there was an overall rise to 9,500BP, which was followed by a dramatic downsizing from 9,000BP. The shift backwards, in terms of average territory population potential at 8,500BP, is rapid and pronounced and represents only 40% of the total average territory population potential for 9,500BP. Although slightly earlier, this parallels the effect observed for the whole of the study area from the qualitative model. Additionally, the catchments at 8,500BP are on average some 25km^2 smaller in land area than their 9,500BP counterparts. This almost certainly is a reflection of sea level rise. Given this reduction in terrestrial catchment size, it is perhaps not surprising that the maxima population density for these predicted sites is seen to decrease.

It is interesting to note that the potential maxima population density rise from 8,500BP to 8,000BP is not as marked as it was in the overall qualitative model. The qualitative catchment results are only 25% higher, as opposed to the 111% increase in the main model (Table 5.6). This disparity is caused by a surface effect, since the catchments are sufficiently small enough not to be overly affected by the increase in coastline length which appears in the main results. This insight suggests the possibility that whilst the overall maximum supportable population density significantly rose per square kilometre, the actual local perception of this rise may have been significantly less. This result has important

implications for the level of occupation within the region which was perceived to be

sustainable by Mesolithic groups.

7.2.5 Overall result summary

The results of this thesis are significant in light of the population pressures present within

the archaeological record **(Objective 3.3 and 3.4)**. The results as presented for this thesis

show quite clearly a rapid loss in population potential between 9,000BP and 8,500BP

(Figure 5.36). Although the qualitative model is unable to produce absolute figures for this

loss, the ratios are large. The figures suggest a 63% loss in population potential between

9,000BP and 8,500BP, and a further 21% loss between 8,000BP and 7,500BP. Such figures

represent huge changes in the potential scale and level of population in this area.

Considering the wider impact, it is apparent that the potential large volumes of displaced

persons proceeding into the surrounding areas of Britain and Europe could well represent

the pressures observed in the archaeological record (Chapter 6).

7.3   Comments on approach

7.3.1 Comments on approach: Available evidence

As with all models, the model generated by this thesis benefits from the virtue that it can be refined and further improved as data becomes available. Whilst working on the thesis, for example, it became apparent that the environmental base data was less than perfect. This is attributed to the low number of cores which have yielded relevant material, and even fewer that have been processed archaeoenvironmentally (Gaffney *et al.* 2007). This situation occurs due to the geological focus of many of the research programs in this region which have little archaeological input (Coles 1998). This thesis, and the mapping techniques developed from it, will allow for the targeting of cores in key locations. It is hoped that the identification of need for this data will help support the research justification for future sampling programs within this region. Any data gathered could be utilised to improve the methodology and data of future versions of this model.

Additionally, should new archaeological finds or further information emerge for this region, probably due to offshore development works, it would be possible to incorporate refinements in the model. This mode of working may facilitate a positive feedback situation, whereby the increase in knowledge generated feeds back to improved models, and hence improved archaeological identification. However, such utilisation must be undertaken with care to ensure balance is sustained and that the model does not become a "self fulfilling" prophecy. Furthermore, the consideration of the landscape provides an opportunity to place the sparse finds in this area in their context.

7.3.2 Comments on approach: Sea level curves and index points

The findings of this work may offer future opportunities to allow the generation of a new set of models which would further enhance and test the original results generated by this thesis. One hindrance to this situation, and to the model, is that sea level models are still coarse in terms of their resolutions (Ward *et al.* 2008). This is especially true within the study area where there are virtually no control points, either spatially and/or temporally (see Shennan 2000 for example). Thus, all of the sea level curves for this region are in effect estimated rather than recorded results.

The search for new sea level index points is therefore a significant requirement. Establishment of these would remove a considerable potential source of error within the thesis model and the archaeological study. Recently, the accuracy of regional sea level curves has been questioned, with major differences being observed at a far more localised scale of about 50km^2 (Kiden *et al.* 2002). If small scale changes such as this occur within the study area, and this is extremely probable, then the effects over the whole of the study area would be noticeable. However, due to the prevailing topographic conditions in the study area the error produced by the model is likely to be low. This is due to the significant vertical scale of features such as the Outer Silver Pit and Dogger Bank, which would be less affected by small scale changes. Conversely areas of low relief to the south of the study area would be much more affected discrepancies in the sea level. Thus, the predominant effect for the study area and the model is that this uncertainty is tending towards being a temporal, rather than a spatial factor.

Observed temporal uncertainty could have an important affect on the results predicted by

this model. Any variations in the sea level model alter the timing of the events observed.

For example, an earlier rise in sea level would produce a population push which is earlier

than currently predicted (10,000BP rather than the 9,000BP observed). Additionally, a

change in rate of rise would also produce a noticeable effect. A slower rise would produce

a more spread out "push" whilst a more rapid rise would produce a more pronounced one.

As such, sea level rise may well represent the biggest uncertainty within the model, and the

resolution of these issues would therefore facilitate greater certainty within the results. In

addition this would facilitate greater accuracy in the chronological correlation to the

existing terrestrial archaeological record. The resolution of this issue would also provide

important data to further refine sea level models for this area. The research has identified

areas which could have been coastline and/or estuary, and thus provides an opportunity to

target the recovery of material. As observed in the introduction, such material would

enable the hypothesis to be tested and considered.

7.3.3 Comments on approach: Computational improvements

One of the most time consuming elements of this study was the need to generate and

convert data from the raw seismic data. As observed in Chapter 3, generation of some of

the data layers could take days. Clearly, this limited the time available to produce and

refine the predictive model. This computational restraint limited the opportunity to further

processing the data to alleviate for areas of poor data visibility. As observed in Chapter 4, it

was these areas which necessitated a limitation on the spatial extent of the predictive

model. The resolution of this would obviously allow for a much greater application of the

model, and further refine the predictive methodology. New developments in seismic

processing and computer power, specifically the shift to 64bit computing, now suggest that

this refinement may be achievable. Furthermore, the improving cross-compatibility

situation between GIS and seismic interpretation programs may well see additional

refinements (Fitch *et al.* 2007). Such a reduction in process time for some of the stages of

the thesis methodology processes suggests that it may be possible to resolve this issue

within the near future.

7.3.4 Comments on approach: Qualitative model assumptions

The qualitative model itself makes a number of assumptions on the prey species. The

scarcity of data and limited evidence make determination problematic. For example, prey

species size and aggregation are based on modern equivalents. All northern European

species have been affected by anthropogenic factors. This determination is true for any

model of this type, qualitative or quantitative. An example of this was discussed with

respect to the seal populations.

The situation is more pronounced for plant species. Indeed, the lack of data available for

plant species and their utilisation, require them to be ignored within the model. The

situation is such that, for the study area, the inclusion of this factor within the model would

be ultimately pure speculation. If suitable archaeoenvironmental evidence could be

provisioned for this area, then it may be possible to take the flora into consideration.

Zvelebili (1994) demonstrates how this could be achieved for the Mesolithic. However, the

achievement of suitable distribution and succession of species would still be problematic. Artificial life models (e.g. Ch'ng 2009) may offer a solution to this issue, should sufficient data be forthcoming.

As we are unable to directly observe and measure Mesolithic procurement and strategies, surrogate information is required in all these instances. It is important to consider that all models, especially in this region, will require this. Yet, it is important to realise that entirely for these reasons, a quantitative precision would therefore be inappropriate. The requirements for assumptions on comparability of prey, habitat, technology etc. would, in effect, be crude estimates. This is because the comparability of these values to those of the past is unknown. The very nature of quantitative modelling therefore is such that it would have suffered greatly under the prevailing data conditions.

The strength of qualitative modelling under this situation is clear. Through the seeking of general relationships and ratios, a more robust situation occurs. Such a situation occurs for this thesis due to the prevailing data conditions. Whilst this approach does not produce precise numbers, the more general nature of the produced ratios allows for greater certainty in their likely applicability. Indeed, it is perhaps important to note that for all the reasons stated, qualitative modelling offers potentially the only way forward at present in this region.

7.4   Research legacy

Elements of this work have been presented at various conferences including the "Seabed and Shallow Marine Geoscience" conference at the Geological society (2004), European Archaeologist Association, Submerged Landscapes session (2007), and The Northern Hunter Gatherer Research Forum (Sheffield 2008). In addition, the geophysical interpretation methodology has been published briefly (Fitch 2005), whilst a discussion of this and the issues involved has been published (Fitch 2007).

The results of the landscape interpretation work, as presented here, have been integrated into a number of other projects, and have acted as a basis for future work and management. As a direct result of the derivation of the geophysical methodology presented in this thesis, further additional research has been further developed in relation to submerged landscape mapping (Gaffney *et al.* 2007). The landscape narrative of the region drawn from the resultant mapping has also been published (Gaffney, Fitch and Smith 2009).

The derived landscape mapping methodology is also assisting research in other landscapes. Research applications are now currently occurring within the Arabian Gulf (Cutler *et al.* 2010, Fitch *et al.* 2009), the Irish Sea (Fitch *et al.* forthcoming). Additionally, further targeted geophysics and sampling associated with the identification of the landscape and environments identified in this thesis is being undertaken, and will shortly be published (Fitch *et al.* forthcoming). It is hoped that this future sampling will provide additional data with which to improve the methodologies outlined in this thesis.

Improvements to the landscape mapping methodology will be applied to the Dutch Sector in a comprehensive manner, similar to that undertaken as part of the NSPP. These Dutch landscapes were first identified in this thesis (see Chapter 6). This identification has highlighted the applicability of the methodology in this area; in response to this identification, funding for a comparative project has been provided by NOAA (National Oceanographic and Atmospheric Administration). This project will commence August 2010 and will seek to further develop the methodology for the North Sea, as well as mapping the landscape of the Dutch sector. Additionally, the methodology will be applied to higher resolution datasets from the Arabian Gulf.

7.5 Future research implications: Introduction

The impacts of this research are perhaps most rapidly realised in Europe and the North Sea.

Indeed, ongoing research by the author in the Dutch Sector of the southern North Sea

demonstrates that similar landscapes exist in these areas (Figure 7.1). However, there are

many marine areas with comparable histories which have also been subject to mineral

exploration. These could also benefit from similar research programmes. Indeed, as

observed above, research is now beginning in the Arabian Gulf. There are, however, other

areas where it would be possible to undertake comparable work. In doing so, it would be

possible to develop the methodologies presented in this thesis. The provision of data in

these areas would encourage other archaeologists to consider the significance of

submerged prehistoric landscapes in wider interpretative schemes.
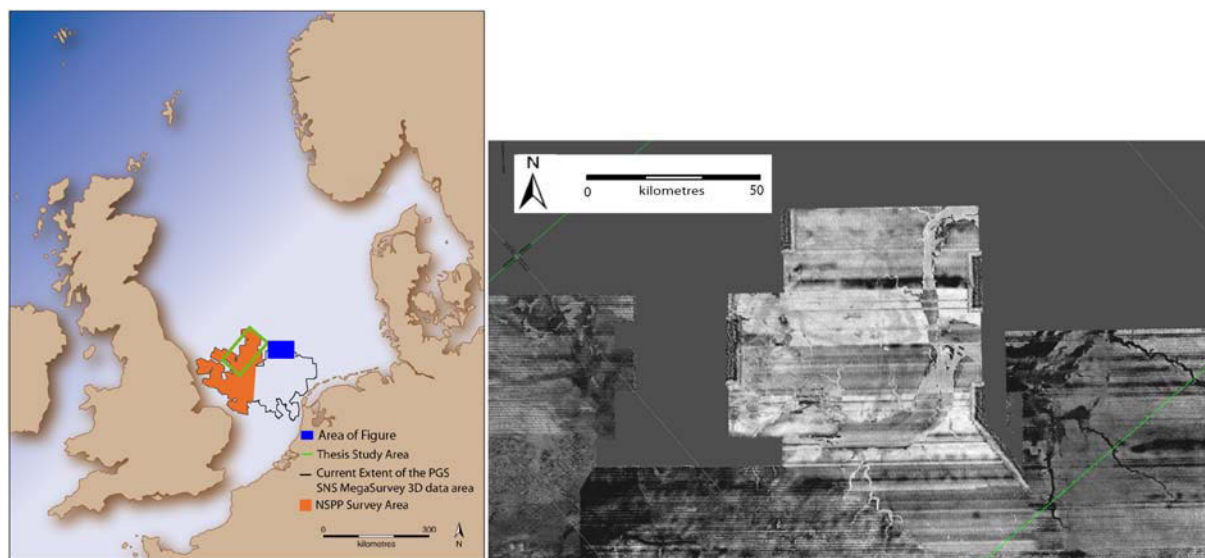
Figure 7.1 A seismic time slice (0.076s, amplitude) through the Dutch Sector of the
southern North Sea. This image clearly reveals a large palaeochannel similar to those
investigated in this research.

7.5.1 Gulf of Mexico

At present, apart from Europe, the most active area with respect to submarine prehistoric archaeological research, is the Gulf of Mexico. Within this region prehistoric Native America sites dating to the end of the last ice age have been mainly discovered at or above the -40m water mark, however deeper sites down to -120m remain possible (Donoghue *et al.* 1995, Faught 2004)(Figure 7.2). Most of the discoveries have been made because of the requirement of the National Historic Preservation Act (NHPA) 1966 to ensure that archaeological information is not lost through activities permitted by Federal agencies. This legislation, therefore, requires the performance of archaeological surveys of the seafloor before the construction of seabed engineering structures related to the extraction of oil and gas within the area.
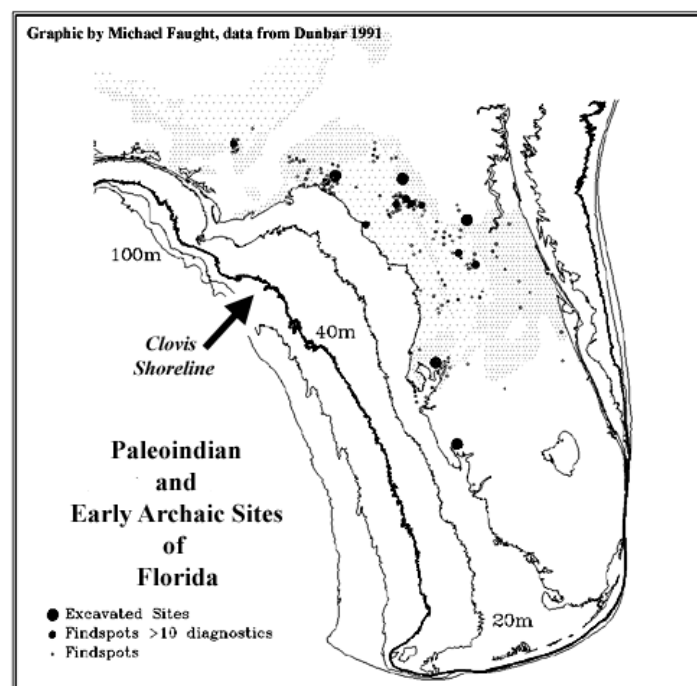
Figure 7.2 Location of the Palaeoshoreline in the Gulf of Mexico next to Florida. Note that the landscape is represented as a single bathymetric outline similar to early representations of Doggerland in the North Sea. (from Faught 2004).

It is notable that most of the discoveries within this region have been made with application of remotely sensed techniques. Especially significant, is the use of high resolution 2D seismic survey to locate and define human occupation sites (Stright 1986). In the gulf of florida targeting of these sites has been aided by the similarity of submerged prehistoric sites with relation to karst geologic features identical to those onshore. This makes it possible to find analogous situations for archaeological survey. However, this approach is limited by the significant landscape differences that do occur in areas further offshore (Tobon 2002). The burial of landscape features by modern sedimentation is also an issue (Tobon 2002). The need for a reliable model therefore is still present. Bennett and Stright (1999) have utilised nearest neighbour tests on coastal archaeological material, using GIS, to assess the potential for the production of such a model. Whilst the data displayed much randomness, some temporal and physical (e.g. type of artefact) attributes demonstrated clustering patterns. In spite of this work, a reliable predictive tool for offshore locations of high archaeological potential remains as yet unrealised, and there is a real potential for the application of a model based on this thesis

This, perhaps, highlights the importance of the more landscape based approach used by this thesis. Whilst the studies of the Gulf of Mexico are reasonably advanced, they are still heavily site focused and are unable to provide a larger landscape archaeological picture. Furthermore, the few finds discovered have been made through the transplanting of knowledge from the present terrestrial archaeological record to the offshore zones. This offers the spectre of a "self-fulfilling" prophecy with respect to the archaeological site type

located and the nature of the material recovered. Unfortunately, there has yet to be an assessment of the archaeological potential of the zones outside these terrestrial analogues. Thus, an understanding of the full potential of this area has yet to be realised. The provision of archaeological landscape information, therefore, would be an invaluable asset to research in this region. This would be achieved through the provision of context to the sites found. In addition, an assessment of their position and perhaps importance within the landscape could also be achieved. The data needed to support the approach used in this thesis presently exists (see Figure 7.3 for PGS dataset coverage for the Gulf of Mexico). Indeed, the Gulf of Mexico is so exceptionally well provisioned with 3D seismic data that it exceeds it in both spatial size and coverage that of the North Sea.
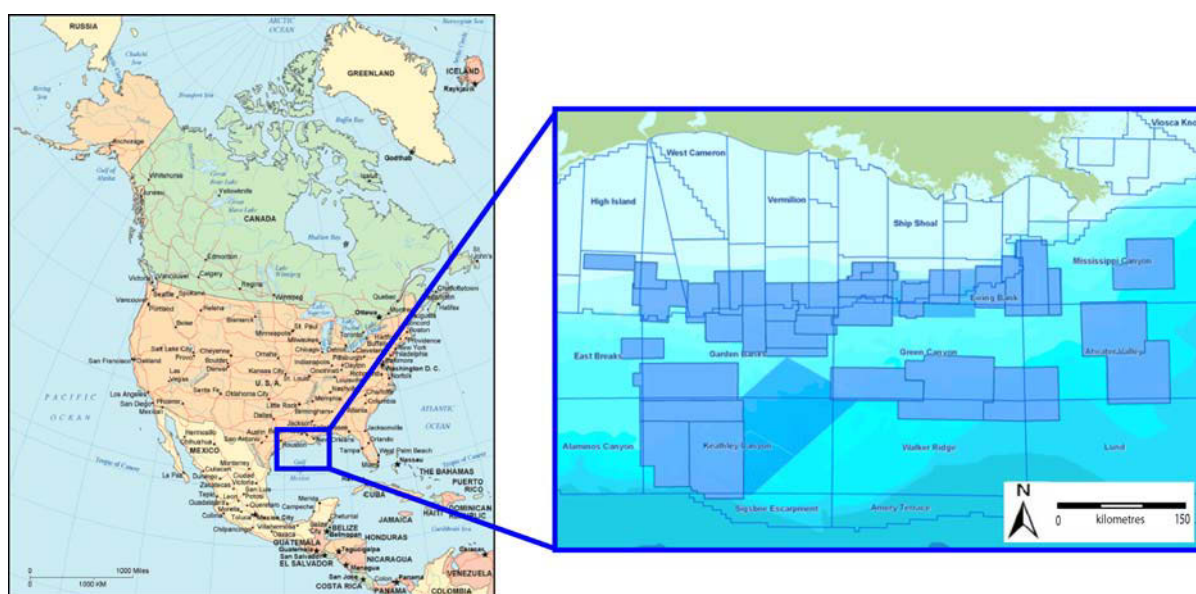
Figure 7.3 PGS datasets (in dark blue) held within the Gulf of Mexico cover a significant proportion of the area which would have been emergent during 12,000BP. It is significant to note that other companies hold datasets which cover many of the areas "missed" by the PGS datasets.

Notably, the coverage of 3D seismic data continues up to the shoreline; this could be almost regarded as a complete coverage. Although this would seem to offer the prospect of a "land to sea" approach to landscape archaeology, caution must be advised. The nearer shore petroleum industry 3D seismic datasets will suffer more intensely from multiples (echoes), because of the shallow water depths. This in turn will limit the resolution of the data. This effect was observed in the data for this thesis study area. Therefore other techniques may be required within this shallow zone. This aside, a significant amount of the data falls within favourable water depths. Thus, it is highly probable that the adoption of the approach developed here could offer considerable benefits to the study of submerged prehistoric archaeology within this region.

7.5.2 Beringia

The Gulf of Mexico has been the focus of investigations of submarine prehistory in America due to the warm sea and available funding. It is, however, only a relatively small fragment of the submerged prehistoric landscape. A significantly more important landscape, in both the human and size criteria is the landscape of Beringia (Figure 7.4). This landscape is named after Vitus Bering, a Danish explorer for the Russian czar in the 18th Century. Bering explored the waters of the North Pacific between Asia and North America. The term "Beringia" is used to geographically describe the vast area delimited by the Kolyma River in the Russian Far East and the Mackenzie River in the Northwest Territories of Canada (Hopkins 1967).
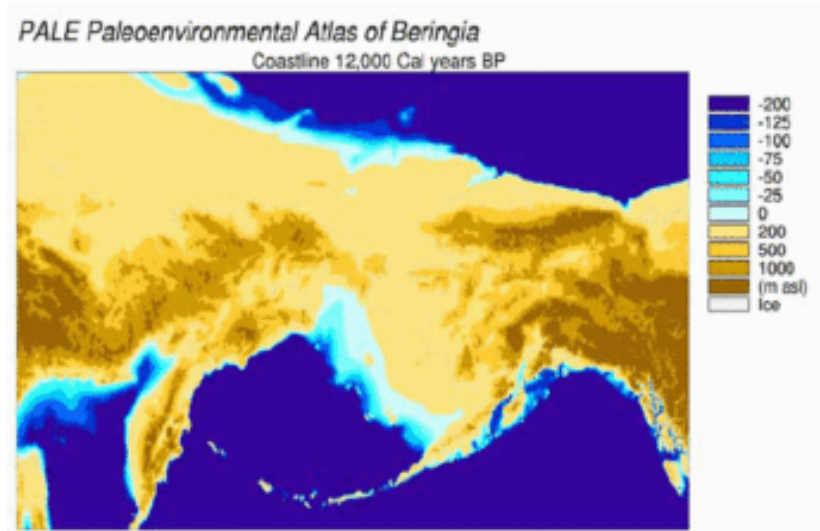
Figure 7.4 Image of the Extents of Beringia during at 12,000 Cal BP. NOAA (2008) – image located at http://www.ncdc.noaa.gov/paleo/parcs/atlas/beringia/lbridge.html.

The landscape of Beringia was formed in a similar fashion to the North Sea. Beringia was last emergent during the last "ice age" when sea levels in the region dropped by up to 120m, creating a 1,000 mile wide grassland steppe, linking Asia and North America. Research in this area is being driven by the needs of biologists to understand the effects of the repeated submergence and emergence of this region on the natural history and the flora and faunal distributions of both Russia and North America. For archaeologists, as one of the world's great ancient crossroads, understanding Beringia's landscape holds solutions to the puzzle regarding which were the first peoples to come to North America. It offers the potential to answer the questions of how and when they travelled to America. Additionally it may explain how they survived under the harsh climatic conditions. Beringia was exposed repeatedly during the climatic fluctuations of the past 40,000 years. This offered numerous opportunities for migration, and has lead to a debate upon the route by which migrating peoples took to populate the Americas.

Crossing Beringia directly would have been possible through an unglaciated "corridor" that existed within the region (Fairbanks 1989 and Table 7.1). This would have provided a possible inland route for human migration. However, it has been suggested that such a crossing would not have been feasible for reasons such as the aridity of the region (Hoffecker and Elias 2003, 39). Additionally, the lack of available fuel for heating would have been an issue (Hoffecker and Elias 2003). Both factors would have formed significant barriers to human occupation in the region.

Dates BP	Beringia	Coastal Route
38,000-34,000	accessible	open
34,000-30,000	submerged	open
30,000-22,000	accessible	closed
22,000-10,000	accessible	open
10,000 BP - Present	submerged	open

Table 7.1 The accessibility of Beringia and the possible coastal route to human migration through time.

It has therefore been suggested that a route along the coastline and islands of Beringia may have been preferable (Erlandson 1994, Carlson 1990). Due to submergence of this area and the inaccessible nature of its location it is likely that this will be hard to resolve. However, there has been recovery of submerged artefacts from this region, for example at Wener Bay, from a fluvial fan at 55m below sea level (Fedje and Christensen 1999). Such a

recovery suggests that travel and occupation along the coastline was indeed possible. Thus, the coastal route may have been the main mode of human occupation and migration within this region.

This information is important in light of the work performed in this thesis. At present, bathymetric coastal contours are being used as analogues for coastlines to guide the search for archaeological material underwater (Fedje and Christensen 1999). However, the need for reliable data remains due to the sedimentation within this region. Indeed, although the area is highly significant, it is important to observe that no landscape detail is available to inform our archaeological opinions. The problem facing Beringia is effectively that which faced Coles when she examined the North Sea in 1998. Studies of the region are therefore effectively limited to an examination of the presence or absence of this landscape (Goebel *et al.* 2008). This limitation prevents the exploration of the effects that landscape features could have had upon the dispersal of modern humans. Thus, the understanding of the nature of this region and its effects on human populations is extremely limited. This, perhaps, can be best displayed in the representation of Beringia, which like the North Sea previous to this thesis, is so often only represented as a bathymetric coastline (see Figure 7.5).

Figure 7.5 A Representation of Beringia as produced by the National Park Services Beringian Heritage program (2008).
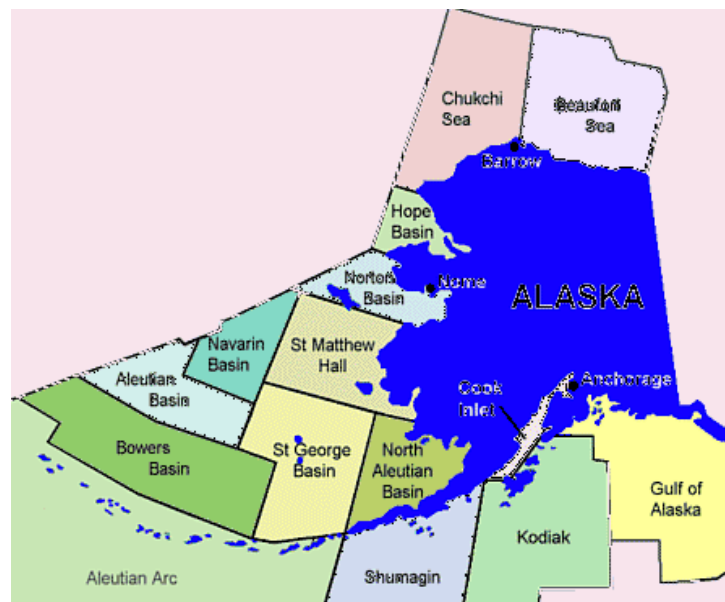
Figure 7.6 Oil and Gas extraction zones around Alaska which cover parts of the former landscape of Beringia (Image Courtesy of Alaska Department of Natural Resources).

Yet, significant areas of the offshore zones of Alaska are now being surveyed for oil and gas (see Figure 7.6). There is an increasing record of seismic survey is being generated that could be utilised for archaeological survey. These data have the potential to provide significant landscape information, in a similar fashion to that presented here in this thesis. Additionally, the utilisation of more modern seismic survey technologies within this region offers the potential for this to be performed at higher resolutions than presented in this thesis. This higher resolution is significant, as it would provide more detailed information on the archaeological landscape of the region. Further, the greater detail provided would allow for a more accurate determination of the nature of population movement through this region. Through the addition of features such as rivers, lakes and hills to this presently blank landscape, it also becomes possible to explore the route ways for this population movement. This greater understanding of route ways, combined with predictive modelling, offers potential for archaeological discoveries in the marine zone, which will be invaluable to the study of Native American archaeology.

7.5.3 Sundaland

Moving south and west from Beringia, the other main submerged prehistoric archaeological landscape encountered is that of Sundaland. Sundaland is defined as the vast inundated area of the South China Sea that includes the Sunda Shelf, linking the shallow coastal shelves of Malaysia with Indonesia, Borneo and the Philippines. This area of submerged landscape is vast, covering over 2 million square kilometres of landscape that would have been available for human occupation during the last glacial maximum.

319
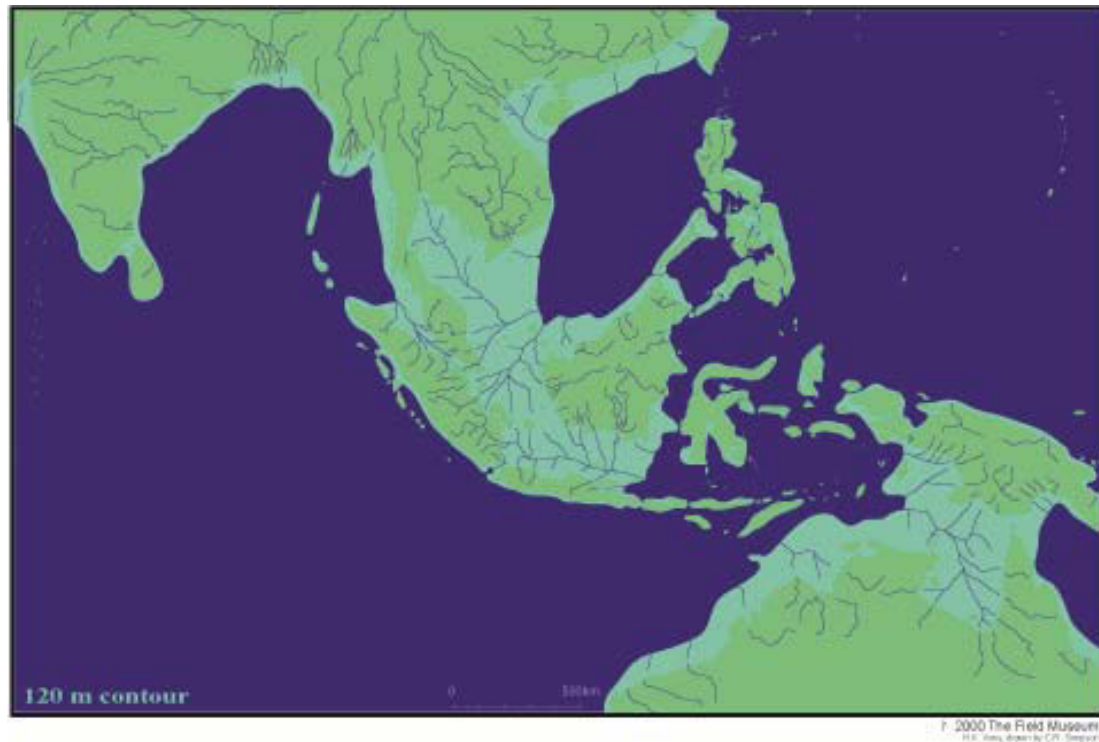
Figure 7.7 The maximum extent of Sundaland and its palaeorivers, based on bathymetry and land above the -120m contour line (After Voris 2000).

As sea levels rose after the last glacial maximum, Sundaland was inundated, with the main loss of landscape occurring in the period from 12,000BC to 9,500BC region. The effect upon the region from the loss of such a landscape was immense, changing global marine circulation currents through the creation of the Indonesian throughflow. The impacts resulting from the submergence and the eventual creation of this marine circulation can be observed in wide-ranging effects varying from major changes in monsoonal position, to the evolutionary changes in species of marine fish (Hirst and Godfrey 1993, Pelejero *et al.* 1999, Song *et al.* 2004, Sathiamurty and Voris 2006).

The landscape and palaeo-rivers of Sundaland were traced via bathymetry by Voris (2000) (see Figure 7.7). Although resembling Coles (1998) Doggerland maps, it is significant to

note that Voris' maps are based upon more recent survey information than Coles

speculative maps of 1998. Voris' maps are dominated by the large "Molengraaff River",

named in honour of the Dutch geologist and explorer. However, many landscape features

remain buried by more recent sediments. This is illustrated the 2D seismic survey, which

has been undertaken within this region (Figure 7.8). Whilst the specific interest of the

survey was Earth Science (Hanebuth and Stattegger 2004), the identification of Holocene

channels has archaeological importance. Indeed, the presence of these features and their

lack of topographic expression suggest that the landscape is considerably more detailed

than previously mapped.
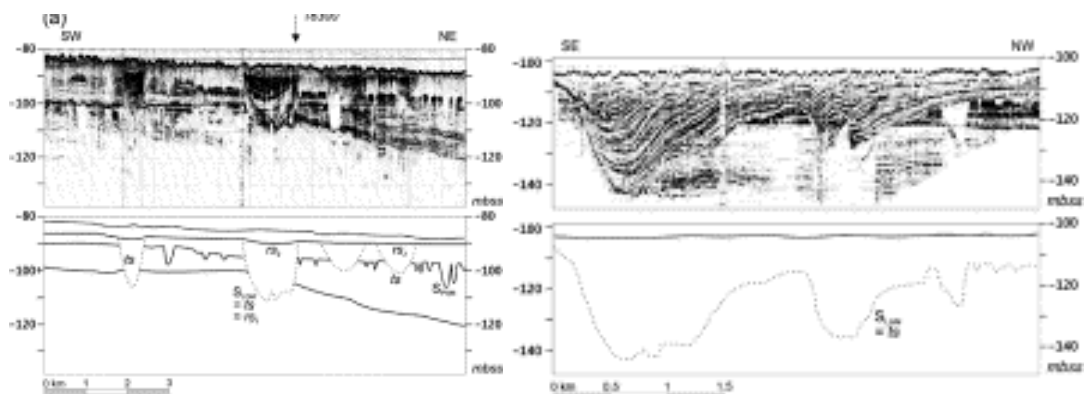
Figure 7.8 Seismic profiles (from Hanebuth and Stattegger 2004) which display typical
patterns of depositional units and erosional surfaces. Arrows mark the position of a core
sample taken during this survey. Note that poor reproduction is due to the original figure
quality.

The 2004 survey led to a sediment coring campaign which revealed the environment of the region. This effectively tells the story of the last days of Sundaland as four successive periods:

1. A subaerial part of a delta plain (oldest)

2. Intertidal mangrove swamps

3. Shallow-marine deposits containing tidally induced laminations

4. Deposits, indicative of open-marine conditions (youngest)

Voris improved his maps in (2006) based on this and other core information. This revealed two significant lakes (see Figure 7.9) and improved the topographic representation of the landscape. However, even with these improved maps, finer palaeochannels are not recorded. Thus the mapping still represents a fairly coarse resolution. This fact is revealed, in part, by the linearity of the river in Figure 7.9.

However, it may be possible to achieve better results; Sundaland itself also possesses a large and growing record of petroleum industry seismic data (Figure 7.10). It is significant to note that the location and existence of much of this information is hard to obtain. This is primarily due to the need for commercial secrecy regarding this emerging resource. It is correct to state, however, that there is an extensive archive of 2D and 3D datasets that could be used to improve on Voris's work. As shown by Hanebuth and Stattegger 2004, seismic data from this region can resolve these features. Interestingly, because of the depth of sedimentation it will be possible to provide a series of archaeologically significant, but temporally distinct landscapes within the same dataset.

322
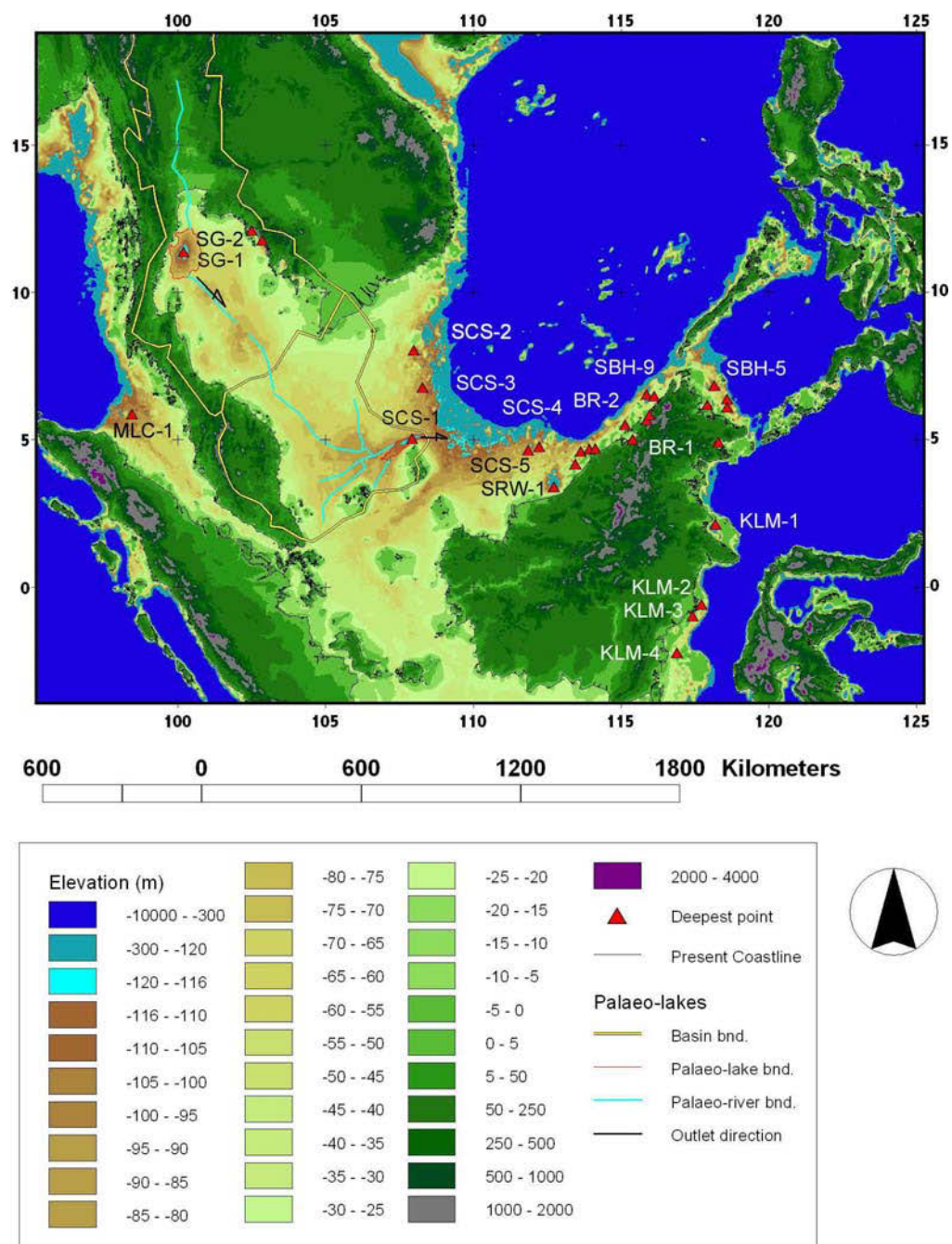
Figure 7.9 The location of two major Palaeolakes located within Sundaland (After
Sathiamurthy and Voris 2006) Note that both of these lakes are of a significant size.

The significance of this should not be understated; this region was a significant source of settlement and economic activity within the region. Furthermore, its position on one of the major human migration routes makes the improvement of the understanding of the archaeological landscape of crucial importance to archaeology. More controversial are claims that the flooding of this region was also responsible for the onset of early agriculture in the Near East (Oppenheimer 1999). It is clear, therefore, that a utilisation of available seismic data, in this region in a similar manner to this thesis, would have significant results for world archaeology.
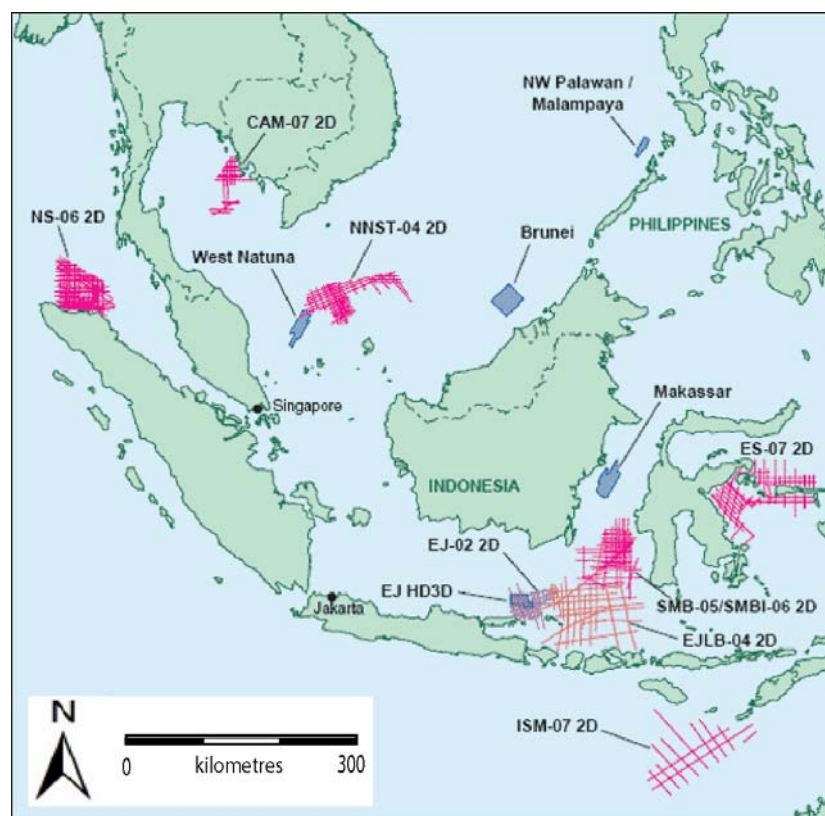
Figure 7.10 PGS seismic survey data for the Southeast Asia region

Therefore, to conclude, it is appropriate to state that the results of this thesis offer many opportunities to further archaeological research around the world. It would, however, be inappropriate to completely transplant the methodology and associated model into these regions. Rather, the approach of the method of application and data derivation are directly relevant. Through such application to these areas of submerged prehistory, this thesis offers the possibility for obtaining previously unobtainable insights into our submerged past.

7.6   Further avenues for future research

As highlighted in Chapter 1 and discussed above, extensive submerged landscapes exist around the world, and it is apparent that vast areas still remain to be surveyed. The North Sea is but one small drop in this prodigious submerged landscape. The potential of this landscape to inform and inspire our future research is great. As Hutton so succinctly puts, the results of this present enquiry is that no end is in sight (Hutton 1788). The avenues of future research presented by this thesis are rightly broad and far reaching, touching most areas of prehistory. In this limited section, however, I will seek only to briefly highlight the most significant, as many have been mentioned throughout this thesis.

Perhaps the most significant ramifications to current archaeological thought are the possibilities presented to understanding the landscape of our past and how humans moved and interacted within it. Human migration is, perhaps, one of the most significant areas where the knowledge of availability of landscape and suitable coastal areas is profoundly

important. The occupation of areas such as America and Australia is tied with the processes and availability of landscapes which are now submerged. Perhaps the most fundamental impact is the knowledge that such data could provide for our understanding of the initial migration of humans from Africa into the rest of the world.

Debate currently exists over the timing and path of the final migration out of Africa; traditionally it has been considered as a progression out of Egypt, up along the Mediterranean coast (Bailey 2004). However, current DNA evidence suggests a different route across the Red Sea, along the coastline of the Yemen, into the Gulf, and then out to the rest of the world (Cutler *et al.* 2010). It is important to observe that this route crosses two major submerged landscapes, both of which have been mapped with seismic data. A clearer understanding of these landscapes, therefore, would greatly assist in our views on the routeways through which this migration occurred. Significantly it could also provide additional data as to why this route was chosen in preference to other alternatives. Other comparable discussions exist around the world (e.g. the timing of the Black Sea flood) which could similarly be resolved.

In addition to the consideration of the spatial element of submerged landscapes, the utilisation of 3D seismic data offers another perspective focal point, the element of time. When examining the data for this thesis, it became apparent that the 3D seismic data contained information relating not only to the spatial extent of the landscape, but also provided an invaluable temporal record of the evolution of the landscape through time. As shown in the Figure 7.11, it is readily apparent that a series of landscapes exist within the

seismic data that predate the Mesolithic landscape visualised within this thesis. These

landscapes relate to earlier periods of prehistory, and record the change in landscape due

to changes in climate and sea-level over time.
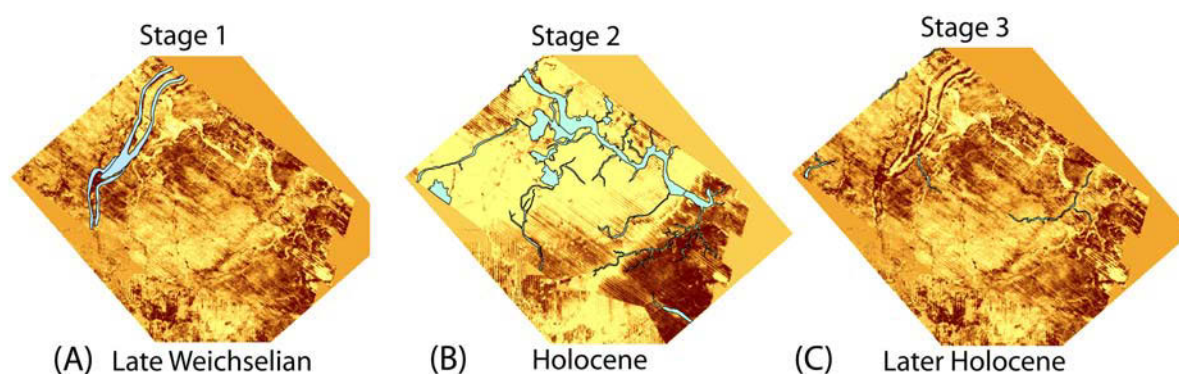
Figure 7.11 3D temporal relationships from Fitch *et al.* 2004.

These Palaeolithic landscapes can be much more easily visualised using 3D seismic data

than their Mesolithic counterparts discussed in this thesis. Due to the optimisations to the

acquisition parameters of the seismic data, which are set to explore deeply buried oil and

gas, it is significant to note that the deeper the sediments visualised within the 3D seismic

data are sharper and clearer than those closer to the surface. Sediments relating to the

period of the earliest known occupation of the British Isles, the Yarmouth Roads formation

(800,000BP), can be observed to be deeply buried within the southern North Sea (Cameron

et al. 1992). These sediments are known to contain plant material and peat, which is

considered to be broadly contemporaneous to those contain at the Palaeolithic site of

Pakefield. However, this optimisation is offset by the more complex sequence stratigraphy

which would hinder the research through the requirement for a detailed understanding of

this complexity. Therefore these landscapes do offer an interesting avenue for research.

In conclusion, the future research possibilities offered by the results of this thesis are significant. Not only in spatial scale, which is global, but also in temporal terms. It offers us the opportunity to understand our early past and allow us to further our knowledge of areas now submerged. As observed by Mithen (1999: 55), the Mesolithic is the period of prehistory that most needs innovation in research. The exploration of its submerged heartland is therefore fundamental. Vast areas have been missing from the understanding of the Mesolithic of north western Europe, and research on it remains sorely needed. This thesis highlights the significance of the submerged prehistoric landscape and its occupants, a starting point that it is hoped will be expanded by future research programmes.

In doing so it is hoped that the methodologies presented here encourage other archaeologists to consider the significance of submerged prehistoric landscapes to wider interpretative schemes both in Europe and around the world.

LIST OF REFERENCES

Aaris-Sorensen, K., Petersen, K.S. and Tauber, H. 1990. Danish Finds of Mammoth (*Mammuthus primigenius* (Blumen-bach)), Stratigraphic position, dating and evidence of late Pleistocene environment, *Danmarks Geologiske Undersogelse*, Serie **B14**: pp. 1-44.

Allen, J.R.L. 1997. Subfossil mammalian tracks (Flandrian) in the Severn Estuary, S.W. Britain: mechanics of formation, preservation and distribution, *Philosophical Transactions of the Royal Society of London*, **B353**: pp. 481-518.

Allen, J.R.L. 2000. Holocene coastal lowlands in NW Europe: autocompaction and the uncertain ground. In Pye and Allen (eds), *Coastal and Estuarine Environments: sedimentology, geomorphology and geoarchaeology.* Geological Society, London, Special Publications **175**: pp. 239-252.

Allen, M.J., and Gardiner, J. 2000. *Our Changing Coast: a survey of the intertidal archaeology of Langstone Harbour, Hampshire*. CBA Research Report **124**. York. Council for British Archaeology.

Andersen, S.H. 1973. Overgangen fra aeldre til yngre stenalder i Sydskandinavien set fra en mesolitisk synsvinkel In: Simonsen, P. and Stamso, G. (eds.) Bonde-Veidemann. *Bofast –ikke Bofast i Nordisk Forhistorie*. Tronso Museums Skrifter XIV. Tromso

Andersen, S. 1985. Tybring Vig. A preliminary report on a submerged Ertebolle settlement on the west coast of Fyn. *Journal of Danish Archaeology* **4**: pp. 52-67.

Andersen, S.H. 1989. Norsminde: a "kjøkkenmødding" with late Mesolithic and early Neolithic occupation. *Journal of Danish Archaeology* **8**: pp. 13–40.

Aparico, J. 1992. Los orı´genes de Oliva. *Real Academia de Cultura Valenciana, Aula de Humanidades y Ciencias, Serie Historica* **9**: pp. 75–143.

Arnaud, J. 1989. The Mesolithic communities of the Sado Valley, Portugal, in their ecological setting. In*. Bonsall, C. (ed.). *The Mesolithic in Europe.* Edinburgh: John Donald, pp. 614-631.

Ashmore, P.J. 2004. 'Dating forager communities in Scotland', In: Saville, A (ed.). *Mesolithic Scotland and its Neighbours: The Early Holocene Prehistory of Scotland, its British and Irish Context, and some Northern European Perspectives*. Edinburgh (Society of Scottish Antiquaries monograph series): pp. 83–94.

Bahorich, M. and Farmer, S. 1995. The coherence cube. *The Leading Edge,* **14**: pp 1053 - 1058

Bang-Andersen, S. 2003. Southwest Norway at the Pliestocene/Holocene Transition: Landscape Developement, Colonization, Site Types, Settlement Patterns. *Norwegian Archaeological Review.* **36** (1): pp. 5-25.

Bailey, G.N. 1978. Shell middens as indicators of postglacial economies: a territorial perspective, In: Mellars, P.(ed.) *The Early Postglacial Settlement of Northern Europe: An Ecological Perspective*: Pittsburgh (PA): University of Pittsburgh Press. pp.37-63.

Bailey, G.N. 1982. Coasts, lakes and littorals. In Jarman, M.R., Bailey, G.N. and Jarman, H.N. (eds) *European Agriculture.* Cambridge: Cambridge University Press: pp. 72–136.

Bailey, G.N. and Milner, N.J. 2002. Coastal Hunters and Gatherers and social evolution: Marginal or central ? *Before Farming: The Archaeology of Old World Hunter-Gatherers* **3-4** (1): pp. 1-15.

Bailey, G. 2004. The wider significance of submerged archaeological sites and their relevance to world prehistory. In: Flemming, N.C (ed.). *Submarine Prehistoric Archaeology of the North Sea*, CBA Research Report **141**. York: Council for British Archaeology.

Bailey, G.N. 2005. Site catchment analysis. In: Renfrew, C. and Bahn, P. (eds.) *Archaeology: the key concepts*. London. Routledge. pp. 230–5.

Bailey, G. 2010. *Europe's Lost World: the Rediscovery of Doggerland*, by Vince Gaffney, Simon Fitch and David Smith, 2009. York: Council for British Archaeology. CBA Research Report 160,*Cambridge Archaeological Journal,* **20:** pp. 145-146.

Bailey, G., Westley, K., Davies, W., Gaffney, V., Gibbard, P., Firth, A., Flemming, N., Schreve, D., Hosfield, R., White, M. and Bates, M. 2010 *Maritime and Marine Historic Environment Research Framework: Draft Palaeolithic Resource Assessment,* http://www.southampton.ac.uk/archaeology/research/projects/maritime_research_framework.html Accessed: 20/07/2010.

Balson, P.S. and Cameron, T.D.J. 1985. Quaternary mapping offshore East Anglia. *Modern Geology* **9**: pp. 221–239.

Balson, P.S. and Jeffery, D.H. 1991. The glacial sequence of the southern North Sea. In: Ehlers, J. Gibbard, P. and Rose. J. (eds.). *Glacial deposits in Great Britain and Ireland*. Rotterdam, Balkema, pp. 245-254.

Barton, N. 1997. *Stone Age Britain.* London, Batsford/English Heritage.

Barton, R.N.E. 1989. Long Blade Technology in Southern Britain. In: Bonsall, C. (ed.). *The Mesolithic in Europe*. Edinburgh: John Donald. pp. 264-271.

Barton, R.N.E., Berridge, P. J., Walker, M. J. C. and Bevins, R. E. 1995. Persistent places in the Mesolithic landscape: an example from the Black Mountain uplands of South Wales, *Proceedings of the Prehistoric Society*, **61**: pp. 81-116.

Barton, R.N.E. 1997. Fifth interim report on the survey and excavations in the Wye Valley, 1997 and new AMS dating results from Madawg rockshelter. Proceedings of the University of Bristol Spelaeological Society **21** (1): pp.99-108.

Barton, N., and Roberts, A. 2004. The Mesolithic Period in England: Current perspectives and new research. In: Saville, A. (ed.). *Mesolithic Scotland and its Neighbours*. Society of Antiquaries of Scotland.

Becker, C.J. 1951. *Maglemosekultur paa Bornholm*. Aaroger. pp. 97-177.

Behre, K.E. and Menke,B. 1979. Pollenanallyische Untersuchungen an einem Bohrkern der südlichen Doggerbank. *Beiträge zur Meereskunde* **24/25**: pp. 123-129. Deutsche Akademie der Wissenschaften zu Berlin.

Bell, M., Caseldine, A.E and Neumann, H. (eds.), 2000. *Prehistoric Intertidal Archaeology in the Welsh Severn Estuary*, CBA Research Report **120**. York: Council for British Archaeology.

Bell, M. 2000. Environmental archaeology in the Severn Estuary: Progress and Prospects. *Archaeology in the Severn Estuary*, **11**: pp. 69-103.

Bell, M. (ed.) 2007. *Prehistoric Coastal Communities: The Mesolithic in western Britain.* CBA Research Report **149**. York: Council for British Archaeology.

Bell, M., Cobb, H., Fitch, S., Long, A.J., Momber, G., Schulting, R,. Spikens, P., and Warren, G.M 2010. *Maritime and Marine Historic Environment Research Framework: Draft Mesolithic Resource Assessment,* http://www.southampton.ac.uk/archaeology/research/projects/maritime_research_framework.html Accessed: 20/07/2010.

Bell, T., O'Sullivan, A., and Quinn, R. 2006. Discovering ancient landscapes under the sea. *Archaeology Ireland* **20** (2): pp. 12-17.

Bellamy, A.G. 1995. Extension of the British Landmass: evidence from shelf sediment bodies in the English Channel. In: Preece, R.C. (ed.). *Island Britain: a Quaternary perspective*. Geological Society Special Publication **96**: pp. 47-62.

Bennett, K.D., Peglar, S.M. and Sharp, M.J. 1991. Holocene Lake Sediments in Central East Anglia. In: Lewis, S.G., Whiteman, C.A. and Bridgland, D.R. (eds.). *Central East Anglia and the Fen Basin Field Guide*. Quaternary Research Association Field Guide, pp. 111-119.

Bennike, O, Jensen, J.B., Lemke, W., Kuijpers, A. and Lomholt, S. 2004 (February). Late and postglacial history of the Great Belt, Denmark. *Boreas*, **33**: pp. 18–33.

Bertrand, A. and MacBeth, C. 2003. Seawater velocity variations and real-time reservoir monitoring. *The Leading Edge*. **22**(4): pp. 351-355.

Bettinger, R.L. 1980. Explanatory/predictive models of hunter-gatherer adaptation.*Advances in Archaeological Method and Theory* **3**: pp.189-255.

Binford, L.R. 1980. Willow Smoke and Dog's Tails: Hunter-Gatherer Settlement Systems and Archaeological Site Formation. *American Antiquity* **45**(1): pp. 4-20.

Birdsell, J.B 1968. Some Predictions for Pleistocene, based on Equilibrium Systems among Recent Hunter-Gatherers. In: Lee, R.B and DeVore, I. (eds.). *Man the Hunter*. Aldine. Chicago.

Birks, H.J.B**.** 1989. Holocene Isochrone Maps and Patterns of Tree Spreading in the British Isles. *Journal of Biogeography* **16.** pp. 503-540.

Binns, A.L. 1980. *Viking Voyagers*. London. Heinemann.

Bjerk, H.B. 1995. The North Sea Continent and the pioneer settlement of Norway. In: A. Fischer (ed.) *Man and Sea in the Mesolithic*. Oxbow. pp. 131- 144.

Bonner, W.N. and Thompson, P.M. 1990. Seals, etc.: Order Pinnipedia – common seal, In: Harris, S. and Corbet, G B. (eds). *The Handbook of British Mammals.* Blackwells, Oxford: pp. 462–471.

Boomer, I., Waddington, C., Stevenson, T., and Hamilton, D. 2007. Holocene coastal change and geoarchaeology at Howick, Northumberland, UK*. The Holocene* **17** (1): pp. 89-104.

Brandt, R., Groenewoudt, B.J and Kvamme, K.L. 1992. An experiment in archaeological site location: modelling in the Netherlands using GIS techniques. *World Archaeology* **2**: pp. 268-282.

Briggs, K., Thomson, K. and Gaffney, V.L. 2007. A Geomorphological Investigation of Submerged Depositional Features within the Outer Silver Pit, southern North Sea. In: Gaffney, V., Thomson, K. and Fitch, S. (eds.). *Mapping Doggerland: The Mesolithic Landscapes of the Southern North Sea*. Archaeopress. Oxford.

Brunstrom, R.G.W. and Walmsley, P.J. 1969. Permian evaporites in the North Sea Basin. *American Association of Petroleum Geologists Bulletin*. **53**(4): pp. 870–883.

Bulat, J. 2005. Some considerations on the interpretation of seabed images based on commercial 3D seismic in the Faroe-Shetland Channel. *Basin Research* **17**: pp. 21-42.

Bunch, M., Gaffney, V.L and Thomson, K. 2007. Coordinating Marine Survey Data Sources. In: Gaffney, V., Thomson, K. and Fitch, S. (eds.). *Mapping Doggerland: The Mesolithic Landscapes of the Southern North Sea*. Archaeopress. Oxford.

Buteux, S., Gaffney, V., White, R., and Van Leusen, M. 2000. Wroxeter Hinterland Project and geophysical survey at Wroxeter. *Archaeological Prospection* **7**: pp.69-80.

Cameron, T.D.J., Crosby, A., Balson, P.S., Jeffery, D.H., Lott, G.K., Bulat, J., and Harrison, D.J. 1992. *United Kingdom offshore regional report: the geology of the Southern North Sea*. HMSO for the British Geological Survey.

Carlson, R.L. 1990. Cultural Antecedents. In: Suttles W. (ed.). *Handbook of North America Indias, vol 7: The Northwest Coast,* Smithsonian Instutution, Washington D.C.: pp. 197-202.

Carlsson, T., Anders, K., and Larsson, M. 1999. Man and the Landscape in the Mesolithic: Aspects of Mental and Physical Settlement Organization. In: Boaz, J. (ed.) *The Mesolithic of Central Scandinavia*. Oslo. Pp. 47-72.

Chapman, H.P., Fletcher, W.G. and Thomas, G. 2001. Quantifying the effects of erosion on archaeology of intertidal environments: a new approach and its implications for their management. *Conservation and Management of Archaeological Sites* **4**: pp. 233-240.

Chapman, H. 2006. *Landscape Archaeology and GIS.* History Press Ltd.

Chatterton, R. 2006. "Ritual" In: Conneller C. and Warren G. (eds.). *Mesolithic Britain and Ireland; new approaches*, Tempus, Stroud.

Chopra, S. 2002. Coherence Cube and beyond. *First Break,* **20** (1): pp 27-33

Ch'ng, E. 2009. An Artificial Life-Based Vegetation Modelling Approach for Biodiversity Research, In: Chiong R. (ed.) *Nature-Inspired informatics for Intelligent Applications and Knowledge Discovery: Implications in Business, Science and Engineering*, IGI Global: Hershey, PA.

Christensen, C. 1990. Stone Age Dug-out Boats in Denmark: Occurrence, Age, Form and Reconstruction. In: Robinson, D.E. (ed.). *Symposia of the Association for Environmental Archaeology* **9**, Oxbow Books.

Church, T., Brandon, R.J. and Burgett, G.R. 2000. GIS Applications in Archaeology: Method in Search of Theory, In: Wescott, K.L. and Brandon, R.J. (eds.) *Practical applications of GIS for archaeologists : a predictive modeling toolkit*. Taylor and Francis, London; Philadelphia.

Churchill, D.M. 1965. The Kitchen midden site at Westward Ho!, Devon. *Proceedings of the Prehistoric Society*, **31**: pp. 74-84.

Clark, J.G.D. 1936. *The Mesolithic Settlement of Europe*. Cambridge University Press, Cambridge.

Clark, J.G.D. 1946. *Seal-hunting in the Stone Age* of north-western Europe: a study in economic prehistory, *Proceedings of the Prehistoric Society* **12**: pp. 12–48.

Clark, J.G.D. 1947. Whales as an economic factor in prehistoric Europe. *Antiquity*, **21**: pp. 84–104.

Clark, J.G.D. 1952. *Prehistoric Europe: the Economic basis.* Cambridge: Cambridge University Press.

Clark, J.G.D. 1954. *Excavations at Star Carr*. Cambridge University Press, Cambridge.

Clark, J.G.D. 1955. 'A Microlithic industry from the Cambridgeshire fenland and other industries of Sauveterrian affinities from Britain', *Proceedings of the Prehistoric Society* **21**: pp. 3-20.

Clark, J.G.D. 1974. *Star Carr: a case study in bioarchaeology.* McCaleb Module, No. **10.**

Clark, J.G.D. 1975. *The Earlier Stone Age Settlement of Scandinavia*. Cambridge University Press.

Clark, J.G.D. 1980. *Mesolithic Prelude.* Edinburgh University Press.

Clarke, D. 1978. *Mesolithic Europe: The Economic Basis*. Duckworth.

Clutton-Brock, T.H and Albon, S.D 1989. *Red deer in the Highlands*. BSP Professional Books, Oxford.

Coles, J.M. 1971. The Early Settlement of Scotland: Excavations at Morton, Fife. *Proceedings of the Prehistoric Society* **37**: pp. 284-366.

Coles, J. and Coles, B. 1995. *Enlarging the Past. The Contribution of Wetland Archaeology* Edinburgh, Society of Antiquaries of Scotland.

Coles, B.J. 1998. Doggerland: a speculative survey. *Proceedings of the Prehistoric Society*. **64**: pp. 45-81.

Coles, B.J. 1999. Doggerland's loss and the Neolithic. In: Coles, B.J, Coles, J. and Schon Jorgensen, M. (eds.) *Bog Bodies, Sacred Sites and Wetland Archaeology*. WARP Occasional Paper. **12**: pp. 51-57.

Coles, B.J. 2000. Doggerland: the cultural dynamics of a shifting coastline. In: Pye, K. and Allen, S.R.L. (eds.) *Coastal and Estuarine Environments: Sedimentology, Geomorphology and Geoarchaeology*: pp. 393-401.

Collins Dictionary 2004. Harper Collins Publishers. London.

Conneller, C. 2004a. Moving beyond sites: Mesolithic technology in the Landscape. In: Milner, N. And Woodman, P. (eds.) *Mesolithic Studies at the Beginning of the 21st Century*. Oxbow Books. Oxford.

Conneller, C.J, 2004b. Becoming deer: corporeal transformations at Star Carr, *Archaeological Dialogues*, **11**(1): pp. 37-56.

Conneller, C. 2006. Death, In: *Mesolithic Britain and Ireland: New Approaches.* Conneller, C. and Warren, G. (eds.). Tempus. Stroud.

Conneller, C. and Warren, G. (eds.) 2006. *Mesolithic Britain and Ireland: New Approaches.* Tempus. Stroud.

Connolly, J., and Lake, M. 2006. *Geographical Information Systems in Archaeology*. Manuals in Archaeology. Cambridge, UK: Cambridge University Press.

Cook,J. and Jacobi, R. 1994. 'A Reindeer antler of 'Lyngby' axe from Northamptonshire and its context in the British Late Glacial'. *Proceedings of the Prehistoric Society* **60**: pp 75-84.

Coulson, T, Guinness, F, Pemberton, J, and Clutton-Brock, T 2004. The demographic consequences of releasing a population of red deer from culling. *Ecology*, **85**: pp. 411-422.

Cowrie 2010. *Offshore Geotechnical Investigations and Historic Environment Analysis: Guidance for the Renewable Energy Sector*. Draft document

Cuttler, R., Fitch, S. and Al-Naimi, F.A. 2010. Considering the 'Terra Incognita' and the implications for the Cultural Resource Management of the Arabian Gulf Palaeolandscape. In: Potts, D., Al Naboodah, H. and Hellyer, P. (eds.). *Archaeology of the United Arab Emirates: Proceedings of the Second Conference on the Archaeology of the UAE.* Trident press, London

Dark, P. 1998. Lake-edge sequences: results, In: Mellars, P. and Dark, P. (eds.). *Star Carr in Context: New Archaeological and Palaeoecological Investigations at the Early Mesolithic Site of Star Carr, North Yorkshire*. McDonald Institute for Archaeological Research.

David, E. 2006. Contributions of the Bone and Antler Industry for Characterising the Early Mesolithic in Europe. In: Kind, C.J (ed.). *After the Ice.* Konrad. Stuttgart.

Dietz, M., Heide-Jorgensen, P. and Harkonen, T. 1989. Mass deaths of harbor *seals* (Phoca vitulina) in Europe, *Ambio* **18**, pp. 258–264.

Dix, J., Quinn, R., and Westley, K. 2004. *A Re-assessment of the Archaeological Potential of Continental Shelves*. Located at: http://www.arch.soton.ac.uk/Research/Aggregates/shelve-report.htm Accessed: 12/01/2010.

Donoghue, J.F and White, N.M 1995. Late Holocene sea-level change and delta migration, Apalachicola River region, northwest Florida, U.S.A*. Journal of Coastal Research* **11**(3): pp. 651-663

Donovan, D.T. 1965. Holocene origin of erosion hollows in the North Sea. *Challenger Society Annual Report.* **3** (17): pp. 43-44.

Donovan, D.T. 1975. The Geology and origin of the Silver Pit and other closed basins in the North Sea. *Proceedings of the Yorkshire Geological Society.* **39** (2): pp. 267-293.

Duggan*,* A. Haisman, M.F. 1992*. "*Prediction of the metabolic cost of walking with and without loads", *Ergonomics*, **35:** pp. 417 – 426.

Dunbar, J S. 1991. Resource Orientation of Clovis and Suwannee Age Paleoindian Sites in Florida. In: Bonnichsen, R. and Clovis, K.L. (eds.): Origins *and Adaptations*. Center for the Study of the First Americans, Corvallis, Oregon.

Dunnell, R.C., and Dancey, W.S. 1983. *The Siteless Survey: A Regional Scale Data Collection Strategy*. In: *Advances in Archaeological Method and Theory* **6**: pp. 267-287.

Dwyer, P.D. and Minnegal, M. 1985. Andaman Islanders, Pygmies and an extension of Horn's Model. *Human Ecology* **13**: pp. 111-119.

Ebert, D. 2004. *Predictive Modeling and the Ecology of Hunter Gatherers of the Boral Forests of Manitoba*. BAR **S1221,** Archaeopress Oxford.

Edwards, H. and Witney, C. 2002. PGS Mega Surveys - the key to new discoveries in mature areas?. *Tech Link* (PGS Geophysical Publication) **2**(3). http://www.pgs.com/upload/31158/data.pdf (Accessed 22/06/2010).

Ehlers, J., Meyer, K.D. and Stephan, H.J. 1984. Pre-Weichselian glaciations in Northwest Europe. *Quaternary Science Reviews*. **3**: pp. 1-40.

Eisma, D., Jansen, F., Van Weering, T.C.E. 1979. Sea-floor morphology and recent sediment movement in the North Sea. . In: Oele, E., Schuttenhelm, R.T.E. and Wiggers, A.J. (eds.). *The Quaternary history of the North Sea. Acta Universitatis Upsaliensis: Symposium Universitatis Upsaliensis Annum Quingentesimum Celebrantis*: **2:** pp. 217–231.

Emery, D. and Myers, K.J. (eds.) 1996. *Sequence Stratigraphy*. Oxford: Blackwell Science.

Erdbrink, B.D.P and Tacoma, J. 1997. Une calotte humaine date au C14 du basin sud de la Mer du Nord. *L'Anthropologie.* **101:** pp. 541-545.

Erlandson, J.M 1994. *Early Hunter-Gatherers of the California Coast.* Plenum Press. New York.

Fagan, B. 2001. *Grahame Clark: An Intellectual Biography of an Archaeologist.* Westview Press, Cambridge.

Fairbanks, R.G. 1989. A 17,000-year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature* **342**: pp. 637–642.

Fannin, N.G.T. 1991. *Processes and material properties of glacially derived deposits*. Geological Society, London, Engineering Geology Special Publications. Volume **7**: pp. 101-102.

Faught, M.K. 2004. The Underwater Archaeology of Paleolandscapes, Apalachee Bay, Florida. *American Antiquity*. **69** (2): pp. 235-249.

Fedje, D.W., Christensen T. 1999. Modeling Paleoshorelines and Locating Early Holocene Coastal Sites in HaidaGwaii; *American Antiquity*, **64**.

Fenton, A. 1978. *The Northern Isles*: Orkney and Shetland. Tuckwell Press.

Findlow, F.J. and Ericson, J.E. 1980. *Catchment Analysis: Essays on Prehistoric Resource Space.* Department of Anthropology, UCLA.

Fischer, A. and Tauber, H. 1986. New C-14 Datings of Late Paleolithic Cultures from Northwestern Europe. *Journal of Danish Archaeology*. **5.**

Fischer, A. 1988. Exploring submerged Stone Age sites in Denmark – or the field of Mesolithic research is as deep as the ocean. *Mesolithic Miscellany* **9**(1): pp. 9-10

Fischer, A. 1995. An Entrance to the Mesolithic world beneath the Ocean. Status of ten years' work on the Danish sea floor. In: Fischer, A. (ed.) *Man and Sea in the Mesolithic: Coastal settlement above and below present sea level*, Proceedings of the International Symposium, Kalundborg, Denmark 1993. Oxbow. Oxford

Fischer, A., Pedersen, L. 1997. Site records. In: Pedersen, L., Fischer, A., Aaby, B. (eds.), *The Danish Storebælt since the Ice Age*. A/S Storebælt Fixed Link, Copenhagen: pp. 319-324.

Fischer, A. 2004. Submerged Stone Age: Danish examples and North Sea potential. In: Flemming, N.C. (ed.) *Submarine Prehistoric Archaeology of the North Sea*. CBA Research Report **141**: pp.21-36.

Fitch, S., Thomson, K. and Gaffney, V.L. 2005. Late Pleistocene and Holocene depositional systems and the palaeogeography of the Dogger Bank, North Sea. *Quaternary Research* **64**: pp. 185-196.

Fitch, S., Gaffney, V.L. and Thomson, K. 2007. *In Sight of Doggerland: From speculative survey to landscape exploration*. *Internet Archaeology.* **22**. (http://intarch.ac.uk). Accessed: 20/07/2010.

Fitch, S., Cuttler, R., Kallweit, H. and Al-Naimi, F.A. 2009. Reconstruction and the Cultural Resource Management of the Late Pleistocene and Holocene landscapes in the offshore environs of the Gulf. *Offshore Arabia (2009), Proceedings of the Offshore Arabia Conference*, January 11-13 2009, Dubai, United Arab Emirates.

Fitch S., Gearey B.R., Hopla E. and Gaffney V.L. Forthcoming. *Finding Doggerland: Surveying and sampling the archaeo-environmental resource of the southern North Sea*

Flannery, K.V. 1968. Archaeological Systems Theory and Early Mesoamerica. In: Meggars, B.J. (ed.). *Anthropological Archaeology in the Americas*, Washington, D.C.: pp. 67-87.

Flannery, K.V. (ed.) 1976. *The Early Mesoamerican Village*. Academic Press, New York.

Flemming, N.C. and Masters, P.M. (eds.) 1983. *Quaternary coastlines and marine archaeology: towards the prehistory of land bridges and continental shelves*. London : Academic Press.

Flemming, N.C. 2002. *The scope of Strategic Environmental Assessment of North Sea areas SEA3 and SEA2 in regard to prehistoric archaeological remains*. Department of Trade and Industry. Report TR_014.

Flemming, N.C. 2004. *Submarine Prehistoric Archaeology of the North Sea*. CBA Research Report **141**.

Foley, R.A. 1981. Off-Site Archaeology and Human Adaptation in Eastern Africa. Oxford: British Archaeological Research.

Funnel, B.M. 1995. Global sea-level and the (pen-) insularity of late Cenozoic Britain. In: Preece, R.C. (ed.) *Island Britain: a Quaternary Perspe*ctive, London: Geological Society: pp 3 -13.

Gaddy, D.E. 2003. *Introduction to GIS for the Petroleum Industry*. Penwell publishers.

Gleyzer, A., Denisyuk, M., Rimmer, A., Salingar, Y. 2004. "A fast recursive GIS algorithm for computing Strahler stream order in braided and nonbraided networks", *Journal of the American Water Resources Association* **40** (4): 937–946,

Gaffney, V.L. and Tingle, M. 1984. The tyranny of the site: method and theory in field survey, *Scottish archaeological review* **3**: pp. 134-140.

Gaffney, V. and Stancic, Z. 1992. Diodorus Siculus and the island of Hvar, Dalmatia: testing the text with GIS. In G. Lock, and J. Moffett (eds), Computer Applications and Quantitative Methods in Archaeology 1991: Oxford: Tempus Reparatum, British Archaeological Reports International Series **S577**: pp. 113-125.

Gaffney, V., Stancic, Z. and Watson, H. 1995. The impact of GIS on archaeology: a personal perspective. In: Lock, G and Stancic, Z (eds.) *Archaeology and Geographical Information Systems: A European Perspective*, London*:* pp. 211-230.

Gaffney, V. and Van Leusen, M. 1995. 'Postscript – GIS, environmental determinism and archaeology: a parallel text'. In: Lock, G. and Stančić, Z. (eds.) *Archaeology and Geographical Information Systems: A European Perspective*, London: pp. 367-82.

Gaffney, C., Gater, J., Linford, P., Gaffney, V., and White, R. 2000. Large-scale systematic fluxgate gradio-metre at the Roman city of Wroxeter. *Archaeological Prospection* **7**: pp. 81-99.

Gaffney, V., Thomson, K. and Fitch, S. (eds.) 2007. *Mapping Doggerland: The Mesolithic Landscapes of the Southern North Sea*. Archaeopress. Oxford.

Gaffney, V.L, Fitch, S., and Smith, D. 2009. *Europe's Lost World: The rediscovery of Doggerland.* CBA Research Report **160.** York: Council for British Archaeology.

Gibbard, P.L. 1988. The history of the great north-west European rivers during the past three million years. *Philosophical Transactions of the Royal Society of London* **318**: pp. 559-602.

Gibbard, P.L., West, R.G. and Zagwijn, W.H. (eds.) 1991. Early and early Middle Pleistocene correlations in the southern North Sea Basin. *Quaternary Science Reviews*. **10**: pp. 23-52.
Gibbard, P.L. and Lewin, J. 2003. The history of the major rivers of southern Britain during the Tertiary. *Journal of the Geological Society* , **160:** pp. 829-845.

Gill, R. 1997. *Chemical Fundamentals of Geology* (Second Edition). Chapman and Hall. London.

Givoni, B. and Goldman, R.F. 1971a. Predicting metabolic energy cost of activity. *Arch. Environ. Health* **27**: pp. 289-293.

Givoni, B. and Goldman, R.F 1971b. Predicting metabolic energy costs. *Journal of Applied Physiology* **30:** pp. 429-433.

Gleyzer, A.; Denisyuk, M.; Rimmer, A.; Salingar, Y. 2004. "A fast recursive GIS algorithm for computing Strahler stream order in braided and nonbraided networks", *Journal of the American Water Resources Association* **40** (4): pp. 937–946.

Glimmerveen, J., Mol, D., Post, K., Reumer, J.W.F., Van der Plicht, H., de Vos, J., Van Geel, B., Van Reenen, B. and Pals, J.P. 2004. The North Sea project: the first palaeontological, palynological and archaeological results. In: Flemming, N.C. (ed.). *Submarine Prehistoric Archaeology of the North Sea*. CBA Research Report **141**: pp. 21-36.

Gob, A. 1979. *Le mesolithique dans le basin de l'Ourthe*. Societe Wallone de Palethnologie. Liege.

Godwin,, H. and Godwin, M.E. 1933. British Maglemose Harpoon Sites. *Antiquity* **7**(25): pp 36-48.

Godwin, H. 1943. Coastal peat beds of the British Isles and North Sea. *Journal of Ecology* **31**: pp. 199-247.

Godwin, H. 1945. Coastal peat beds of the North Sea region, as indices of land- and sea-level changes. *New Phytologist.* **44**: pp. 29–69.

Godwin, H. 1975. *The History of the British Fauna* (2nd Edition). Cambridge University Press, Cambridge.

Goebel, T., Waters, M.R., O'Rourke, D.H. 2008. "The Late Pleistocene Dispersal of Modern Humans in the Americas". *Science* **319** (5869): pp. 1497–1502.

Gooder J. 2007. Excavation of a Mesolithic House at East Barns, East Lothian. In: Waddington C. and Pedersen K. (eds.) 2007. *Mesolithic Studies in the North Sea Basin and Beyond: Proceedings of a Conference held at Newcastle in 2003*. Oxbow Books.

Gould, S.J. 1991. The Case of the Creeping Fox Terrier Clone. In: Gould, S.J. *Bully for Brontosaurus.* Penguin Books. London.

Gramsch, B. 1992. Friesack Mesolithic wetlands In: Coles, B. (ed.) *The Wetland Revolution in Prehistory*, The Prehistoric Society and WARP, University of Exeter: pp.65-72.

Green, E.L. 1973. Location analysis of prehistoric Maya sites in Northern British Honduras. *American Antiquity* **38**(3): pp. 279-293.

Groom, D., and Oxley, I. 2001. Maritime Fife: Managing Fife's underwater heritage: a feasibility study for a maritime archaeological GIS. In: Wheatley, D.W., Earl, G.P. and Poppy, S.J. (eds.). *Contemporary Themes in Archaeological Computing.* Oxbow Books.

Gron, O. and Skaarup, J. 2004. *Mollegabet II: A submerged Mesolithic settlement in southern Denmark.* BAR **S1328** Archaeopress.

Hamblin, R.J.O*., Crosby, A., Balson, P.S., Jones, S.M., Chadwick, R.A., Penn, I.E., and Arthur, M.J., 1992. United Kingdom offshore regional report: The geology of the English Channel*. London, Her Majesty's Stationery Office for the British Geological Survey.

Hanebuth, T.J.J. and Stattegger, K. 2004. Depositional sequences on a late Pleistocene–Holocene tropical siliciclastic shelf (Sunda Shelf, southeast Asia*) Journal of Asian Earth Sciences* , **23**(1): pp 113-126.

Heide-Jorgensen, M.P., Harkonen, T., Dietz, R. and Thompson, P.M. 1992. Retrospective of the 1988 European seal epizootic. *Diseases of Auqatic Organisms*. **13**: pp.37-62.

Higgs, E. and Vita-Finzi, C. 1972. 'Prehistoric economies: a territorial approach', in E. Higgs (ed.) *Papers in Economic Prehistory*, London: pp. 27-36.

Hill, K., Hawkes, K. and Hurtado, A.M. 1987. Foraging decisions among Ache huntergatherers: New data and implications for optimal foraging theory. *Ethology and Sociobiology*, **8:** pp.1-36.

Hiraguchi, T., 1993. *A Study of Jomon-period Dolphin Fishing by an Individual Identification Analysis of Animal Remains: Grant-in Aid for Scientific Research (C)*, Tokyo.

Hirst, A.C., Godfrey, J.S. 1993. The role of Indonesian Throughflow in a Global Ocean GCM. *Journal of Physical Oceanography*. **23**: pp.1057–1086.

Hodder, I. Orton, C. and Renfrew, C. (eds.) 1976. *Spatial Analysis in Archaeology*. Cambridge University Press.

Hoffecker, J.F. and Elias, S.A. 2003. Environment and Archaeology in Beringia. *Evolutionary Anthropology* **12:** pp. 34-49.

Hopkins, D.M (ed.) 1967. *The Bering Land Bridge*. Stanford University Press.
Horton, R.E. 1945. "Erosional development of streams and their drainage basins: hydro-physical approach to quantitative morphology", *Geological Society of America Bulletin* **56** (3): pp. 275–370

Huddart, D., Gonzalez,. S. and Roberts, G. 1999. The archaeological record and mid-Holocene marginal coastal palaeoenvironments around Liverpool bay. In: Edwards, K.J. and Sadler, J.P. (eds.) *Holocene Environments of Prehistoric Britain*, Quaternary Proceedings **7**. John Wiley Publishers.

Hudson, T. 1981. To Sea or not to Sea: Further Notes on the "Oceangoing" Dugouts of North Coastal California. *Journal of California and Great Basin Anthropology*, **3**(2): pp. 269–281

Huntley, B., and Birks, H.J.B. 1983. *An Atlas of Past and Present Pollen Maps of Europe 0-13,000 years ago*. Cambridge University Press, Cambridge.

Hutton, J. 1788. Theory of the Earth; or an investigation of the laws observable in the composition, dissolution, and restoration of land upon the Globe. *Transactions of the Royal Society of Edinburgh*, **1**(2): pp. 209-304.

Indrelid, S. 1978. Mesolithic economy and settlement patterns in Norway. In Mellars, P.A (ed.): *The Mesolithic settlement of Northern Europe.* Pittsburg. pp 147-176.

Jacobi, R.M. 1973. 'Aspects of the Mesolithic Age in Great Britain'. In: Koslowski, S.K. (ed.) *The Mesolithic in Europe*. Warsaw. pp. 237-265.

Jacobi, R. 1976. Britain inside and outside Mesolithic Europe *Proceedings of the Prehistoric Society* **42**: pp. 67-84.

Jacobi, R.M. 1978. The Mesolithic of Sussex. In: Drewett, P.L (ed.) Archaeology in Sussex to AD 1500. Council for British Archaeology Research Report: pp. 29, 15-22.

Jelgersma, S. 1979. Sea-level changes in the North Sea basin. In: Oele, E., Schuttenhelm, R.T.E., and Wiggers, A.J., (eds.). *The Quaternary history of the North Sea*. Acta Universitatis Upsaliensis: Symposium Universitatis Upsaliensis Annum Quingentesimum Celebrantis: **2**: pp. 233-248.

Jensen, J. 1982. *The Prehistory of Denmark*. Methuen and Co. Ltd. London.

Jensen, T., Bildt, M., Dietz, H., Andersen, T.H., Hammer, A.S, Kuiken, T. and Osterhaus, A. 2002. Another Phocine Distemper Outbreak in Europe. *Science.* **297**: pp. 209

Jochim, M. 1976. *Hunter-Gatherer Subsistence and Settlement: A Predictive Model*. London, Academic Press.

Jochim, M.A. 1998. *A Hunter-Gather Landscape, Southwest Germany in the Late Palaeolithic and Mesolithic*. Plenum Press. London.

Johansson, A.D. 1990. *Barmose-Gruppen. Praeboreale Bopladsfiind i Sydsjoelland*. Aarhus: Aarhus Universitetsforlag.

Joon,B., Laban, C. and Meer van der, J.J.M. 1990. The Saalian glaciation in the Dutch part of the North Sea. *Geologie en Mijnbouw* **69**: pp. 151–158.

Julian, F. 1994. Pinniped and cetacean mortality in California gillnet fisheries: Preliminary estimates for 1993. International Whaling Committee Working Paper **SC/46/Oll.**

Kamermans, H. 2000. Land evaluation as predictive modelling: a deductive approach. In: Lock, G (ed.) *Beyond the Map.Archaeology and Spatial Technologies*. NATO Sciences Series. IOS Press. Amsterdam. pp. 124-146.

Kamil, A.C., Krebs, J.R. and Pulliam, H.R. 1987. *Foraging Behavior*, Plenum Press, New York and London.

Karsten, P. and Knarrstrom, B. 2003. *The Tagerup Excavations*. Lund: National Heritage Board.

Keene, A. 1981. Optimal foraging in a nonmarginal environment: a model of prehistoric subsistence strategies in Michigan. In: Winterhalder, B. , Smith, E.A. (eds.) . *Hunter-Gatherer Foraging Strategies.* Chicago: Univ. Chicago Press.

Kidd, G.D. 1999. Fundamentals of 3D seismic volume visualization. *The Leading Edge* **18**: pp. 702-709.

Kiden, P., Denys,. L. and Johnston, P. 2002. Late Quaternary sea-level change and isostatic and tectonic land movements along the Belgian-Dutch North Sea coast: geological data and model results. *Journal of Quaternary Science.* **17**(5-6): pp. 535-546.

Klemperer, S., and Hobbs, R. 1991. *The BIRPS atlas: deep seismic reflection profiles around the British Isles.* Cambridge University Press.

Kohler, T.A. and Parker, S.C. 1986. Predictive Models for Archaeological Resource Location. In: *Advances in Archaeological Method and Theory.* **9**, Academic Press, New York.: pp. 397-452.

Kohler, T.A. 1988. Predictive Locational Modeling: History and Current Practice. In: Judge, W.J. and Sebastian, L. (eds.). *Quantifying the present and predicting the past: Theory, method, and application of archaeological predictive modeling* , U.S. Government Printing Office, Washinton, D.C.

Kolfschoten, T. and Van Essen, H. 2004. Palaeozoological heritage from the bottom of the North Sea. In: Flemming, N.C. (ed.), *Submarine prehistoric archaeology of the North Sea. Research priorities and collaboration with industry*. CBA Research Report **141**, York: English Heritage/Council for British Archaeology: pp. 70-80.

Kooijmans, L.P. 1970/1971. Mesolithic bone and antler implements from the North Sea and from the Netherlands. *Berichtien van de Rijksdienst voor het Oudheidkunde Bodemonderzoek*, **20-21**: pp. 27-73.

Kooijmans, L.P. (ed.) 2001. *A Mesolithic hunting camp in the river (5500-5000 BC.)* (Reporting Archaeological Heritage), 83. Amersfoort: ROB.

Kooijmans, L.P. (ed.) 2001. *Archeologie in de Betuweroute Hardinxveld-Giessendam De Bruin. Een kampplaats uit het Laat-Mesolithicum en het begin van de Swifterbant-cultuur (5500-4450 v. Chr.).*Amersfoort.

Kooijmans, L.P., Broeke, P.W., Van den Fokkens, H. and Gijn, A.L. (eds.) 2005. *De prehistorie van Nederland*. *The prehistory of the Netherlands.* Amsterdam: Prometeus. Amsterdam: Prometheus.

Kozlowski, J.K. and Kozlowski, S.K 1979. Upper Palaeolithic and Mesolithic in Europe, Taxonomy and Palaeohistory. *Prace Komisji Archaeologicznej*, **18.**

Kuiper, J.A., and Wescott, K.L. 1999. *A GIS Approach for Predicting Prehistoric Site Locations,* presented at the 19th Annual ESRI User Conference, San Diego, CA.

Kvamme, K.L. 1985. Determining Empirical Relationships Between the Natural Environment and Prehistoric Site Locations: A Hunter-Gatherer Example. In: Carr, C. (ed.). *For Concordance in Archaeological Analysis*. Westport Publishers, St. Louis. pp. 208-238.

Kvamme, K.L. 1986. The use of geographic information systems for modeling archaeological site distributions. In: Opitz, B.K. and Deepak, A. (eds.) Geographic information systems in government Vol. 1. Hampton, Virginia.

Kvamme, K.L. and Jochim, M.A. 1989. The Environmental Basis of Mesolithic Settlement. In: Bonsall, C. (ed.). *The Mesolithic in Europe: Papers Presented at the Third International Symposium, Edinburgh* 1985. Edinburgh: John Donald Publishers Ltd. pp. 1-12.

Kvamme, K.L. 1990. One-Sample Tests in Regional Archaeological Analysis: New Possibilities through Computer Technology. *American Antiquity* **55**(2): pp. 367-381.

Kvamme, K. and Jochim, M.A. 1990. The Environmental Basis of Mesolithic Settlement. In: Bonsall C. (ed.) *The Mesolithic in Europe: Proceedings of the Third International Symposium, Edinburgh 1985*. University of Edinburgh Press, Edinburgh. pp. 1-12.

Kvamme, K.L. 1992. A Predictive Site Location Model on the High Plains: An Example with an Independent Test. *Plains Anthropologist* **37**(138): pp. 19-40.

Kvamme, K. 2006. Integrating multidimensional geophysical data. *Archaeological Prospection* **13**: pp.57-72.

Laban, C. and Van der Meer, J.J.M., 1990. The Saalian glaciation in the North Sea. *Geologie en Mijnbouw*, **69**: pp. 151-158.

Lacam, R , Niederlender, A. and Vallois H.V. 1944. *Le gisement mesolithique du Cuzoul de Gramat*. Archives de l'Insitut de Paleontologie Humanie. Memoire **21**. Lambeck, K. 1991. Glacial rebound and sea-level change in the British Isles. *Terra Nova, 3*, 379–389.

Lambeck, K. 1995. Predicted Shoreline from Rebound Models. *Journal of the Geological Society* **152**: 437-448.

Lambeck, K. 1998. On the choice of timescale in glacial rebound modelling: mantle viscosity estimates and the radiocarbon timescale, *Geophysics Journal International*, **134**: pp. 647–651.

Lambeck, K. and Purcell, A.P. 2001. Sea-level change in the Irish Sea since the Last Glacial Maximum: constraints from isostatic modelling. *Journal of Quaternary Science.* **16**(5): pp. 497-506.

Laraminie, F.G. 1989a. *Silverwell Sheet (54N 02E): Seabed Sediments and Holocene Geology*. HMSO, London.

Laraminie, F.G. 1989b. *Silverwell Sheet (54N 02E): Quaternary Geology*. HMSO, London

Larsson, L. 1984. *The Skateholm Project: A late Mesolithic settlement and cemetery complex at a southern Swedish bay.* Meddelanden fran Lunds Universitets Historiska Museum 1983-84: pp. 5-46.

Larrson, L. 1990. The Mesolithic of southern Scandinavia. *Journal of World Prehistory* **4**: 257-309.

Lawley, R. and Booth, S. 2004. Skimming the surface, *Geoscientist* **14**: pp. 4–6.

Lee, R.B. and DeVore, I. 1968. Problems in the Study of Hunters and Gatherers. In: Lee, R.B. and DeVore, I. (eds.). *Man the Hunter*. Aldine. Chicago.

Legge, A.J., and Rowley-Conwy, P.A. 1988. *Star Carr Revisited*. BirkBeck College, University of London.

Leopold, L.B., Wolman, M.G. and Miller, J.P. 1964. *Fluvial Processes in Geomorphology*. San Francisco: W.H. Freeman and Company.

Leotard, J.M., Straus, L.G., and Otte, M. 1999. *L'Abri du Pape.* Etudes et Recherches Archeologiques de l'Universite de Liege 88. Liege, Belgium.

Lewis, B.R. and Murphy, S.A. 1981. Central Illinois Unit (IV). In: Brown M.K. (ed.) *Predictive Models in Illinois Archaeology Report Summaries*. Illinois Dept. of Conservation, Division of Historic Sites. pp. 33-40.

Liversage, D. 1992. *Barkaer: Long barrows and settlements.* Arkaeologiske Studier IX. Copenhagen: Akademisk Forlag.

Lonergan, L., Maidment, S.C.R, Collier, J.S. 2006. Pliestocene subglacial teunnel valleys in the central North Sea basin: 3-D morphology and evolution. *Journal of Quaternary Science.* **21**(8): pp. 891 -903.

Long, D. and Stoker, M.S. 1986. Channels in the North Sea: The nature of a hazard. In: *Proceedings of Oceanology International '86 Oceanology* **vol. 6**, Graham and Trotman, London. pp. 339–351.

Long, D, Wickham-Jones, C R and Ruckley, N A, 1986. A flint artefact from the northern North Sea, in D Roe (ed.), *Studies in the Upper Palaeolithic of Britain and North Western Europe*, BAR International Series **296:** pp 55–62.

Long, D., Streif, H., Cameron, T.D.J. and Schuttenhelm, R.T.E. 1988. The sedimentary record of climatic variation in the southern North Sea. *Philosophical Transactions of the Royal Society of London.* Series B. **318**: pp. 523-537.

Lovis, W.A., Whallon, R.and Donahue, R.E. 2006. Social and spatial dimensions of Mesolithic mobility. *Journal of Anthropological Archaeology* **25**: pp.271-274.

Lubke, H. 2003. New Investigations on Submarin Stone Age Settlements in the Wismar Bay Area. In: Larsson, L., Kindgreen, H., Knutsson, K., Loeffler, D. and Akerlund, A. (eds.) 2003. *Mesolithic on the Move. Papers presented at the Sixth International Conference on the Mesolithic in Europe, Stockholm 2000*. Oxford: Oxbow.

Lumsden, G. I. 1986. *California Sheet (54N 0E): Quaternary Geology*. HMSO, London.

MacArthur, R.H. and Pianka, E.R. 1966. *On the optimal use of a patchy environment*. *American Naturalist,* **100.**

McFayden, L. 2006. "Landscape" In: Conneller C. and Warren G. (eds.). *Mesolithic Britain and Ireland; new approaches,* Tempus, Stroud.

Mannino, M.A. and Thomas, K.D. 2002. 'Depletion of a resource? The impact of prehistoric human foraging on intertidal mollusc communities and its significance for human settlement, mobility and dispersal', *World Archaeology* **33**(3): pp. 452–74.

Marble, D.F. 1996. *The Human Effort Involved in Movement over Natural Terrain: A Working Bibliography*, Unpublished report, Department of Geography, Ohio State University.

Martin, J.F. 1983. Optimal foraging theory: a review of some models and their applications*. American Anthropology*. **85**: pp.612-29.

Mattioli S., and Pedone, P. 1995. Dressed versus undressed weight relationship in Wild Boars (Sus scrofa) from Italy*, Journal of Mountain Ecology (IBEX)* **3**: pp. 72-73.

Mellars, P.A and Payne, S**.** 1971. 'The excavation of two mesolithic shell middens on the Island of Oronsay (Inner Hebrides)', *Nature (London),* **231.**

Mellars, P.A. 1974. 'The Paleolithic and the Mesolithic', In: Renfrew, C (ed.) '*British Prehistory: A New Outline*', Duckworth: pp. 41-99.

Mellars, P.A. 1978. *The Early Postglacial Settlement of Northern Europe: an Ecological Perspective.* London : Duckworth.

Mellars, P 2004. 'Mesolithic Scotland, coastal occupation and the role of the Oronsay middens', In: Saville, A (ed.) 2004 *Mesolithic Scotland and its Neighbours: The Early Holocene Prehistory of Scotland, its British and Irish Context, and some Northern European Perspectives*. Edinburgh (Society of Scottish Antiquaries Monograph Series): pp. 167–84.

Mellars, P.A. and Day, S.P. 1994. 'Absolute' dating of Mesolithic human activity at Star Carr, Yorkshire: new palaeoecological studies and identification of the 9600 BP radiocarbon 'plateau'. *Proceedings of the Prehistoric Society* **60:** pp. 194-2000

Mellars M.P and Mellars P.A. 1998. Stable Isotopes and the Seasonality of the Oronsay Midden. *Antiquity,* **72**, pp 178-184

Midgley, M.S. 2005. *The Monumental Cemeteries of Prehistoric Europe*: Tempus. Stroud.

Milner, N., and Woodman, P. 2004. Looking into the canon's mouth: Mesolithic studies in the 21st century. In: Milner, N. and Woodman, P. (eds.) *Mesolithic Studies at the beginning of the 21st Century*. Oxbow. Oxford

Milner, N., and Woodman, P. (eds.) 2004. *Mesolithic studies at the beginning of the 21st Century.* Oxford. Oxbow.

Milner, N. 2006. "Subsistence" In: Conneller, C. and Warren, G. (eds.) *Mesolithic Britain and Ireland; new approaches*, Tempus, Stroud.

Mithen, S.J. 1990. *Thoughtful Foragers: A Study of Prehistoric Decision Making*. Cambridge: Cambridge University Press.

Mithen, S.J. and Finlayson, B. 1991. Red deer hunters on Colonsay? The implications of Staosnaig for the interpretation of the Oronsay Middens. *Proceedings of the Prehistoric Society* **57**(2): pp. 1-8.

Mithen, S. 1999. Hunter-gathers of the Mesolithic. In: Hunter J. and Ralston I. (eds.) *The Archaeology of Britain*. Routledge. pp. 35-58.

Mithen, S.J., Finlay, N., Carruthers, W., Carter, P., and Ashmore, P. 2001. Plant use in the Mesolithic: The case of Staosnaig. *Journal of Archaeological Science* **28**: pp. 223-234.

Mithen, S.J. 2003. *After The Ice: A Global Human History, 20,000-5000 BC*. London: Weidenfeld and Nicolson.

Momber, G. 2000. Drowned and deserted: a submerged prehistoric landscape in the Solent, England, *The International Journal of Nautical Archaeology* **29**(1): pp. 86-99.

Momber, G 2004. The Inundated landscapes of the western Solent. In. Flemming N. C. 2004. *Submarine Prehistoric Archaeology of the North Sea*. CBA Research Report **141**. York. Council for British Archaeology.

Mordant, D. and Mordant, C. 1992. Noyen-Sur-Seine: A Mesolithic Waterside Settlement. In: Coles, B. (ed.) *The Wetland Revolution In Prehistory*. Wetland Archaeological Research Project Occasional Paper 6, Exeter. pp. 55-64.

Morner, N.A. 1976. *Eustatic changes during the last 8,00 years in view of radiocarbon calibration and new information from the Kattegat region and other Northwestern European coastal areas: Palaeogeography, Plalaeoclimatology, Palaeoecology*, v.19

Morrison, A. 1980. *Early Man in Britain and Ireland*, Croom Helm, London.

Natural History Museum 2005. *Out of the Blue*, HMSO, London.

Nordqvist, B. 1995. The Mesolithic settlements of the Swedish west-coast –with special emphasis on chronology and topography of settlements. In: Fischer, A. (ed.) *Man and Sea in the Mesolithic – coastal settlement above and below present sea level.* Oxbow Monograph **53**. Oxford.

Nordqvist, B. 2000. *Coastal Adaptations in the Mesolithic: A study of coastal sites with organic remains from the Boreal and Atlantic periods in Western Sweden.* GOTARC Series B. Gothenburg Archaeological Theses **13**. Goteborg.

North, C.P. 1996. The prediction and modelling of subsurface stratigraphy. In: Carling, P.A and Dawson M.R. (eds.) *Advances in Fluvial Dynamics and Stratigraphy*. Wiley Chichester. pp. 395-508

Northridge, S. 1988*. Marine mammals and fisheries: A study of conflicts with fishing gear in British waters.* Wildlife Link, London.

Novak, B and Bjorck, S. 2002. Late Pleistocene–early Holocene fluvial facies and depositional processes in the Fehmarn Belt, between Germany and Denmark, revealed by high-resolution seismic and lithofacies analysis. *Sedimentology*. **49:** pp 451-465

Nussey, D.H., Pemberton, J., Donald, A., Kruuk, L.E.B. 2006. Genetic consequences of human management in an introduced island population of red deer (*Cervus elaphus*). *Heredity*, **97**: pp. 56-65.

Nygaard, S, 1990. Mesolithic in Western Norway. In: Vermeersch, P.M. and Van Peer, P. (eds.). *Contributions to the Mesolithic in Europe. Papers presented at the fourth international symposium 'The Mesolithic in Europe',* Leuven U.I.S.P.P.. *Studia Praehistorica Belgica*, **5**: pp. 1-480.

Oele, E. 1969. The Quaternary geology of the Dutch part of the North Sea, north of the Frisian Isles. *Geologie en Mijnbouw* **48**: pp. 467-480.
Oppenheimer, S. 1999. *Eden in the East: The drowned continent of Southeast Asia.* Pheonix Publication. London.

Palmer, S. 1976. *A Mesolithic site with structures on the Isle of Portland.* IXe Congr. UISPP, Nice Resumes des Commun. Paris CNRS.

Palmer, S. 1977. *Mesolithic Cultures of Britain*. Dolphin Press.

Pandolf, K.B. 1977. Psychological and physiological factors influencing perceived exertion. In: Borg, G (ed.) *Physical Work and Effort*. Solna. Sweden: Pergamon Press. pp 371-383.

Parker, G. 1976. On the causes and characteristic scales of meandering and braiding rivers. *Journal of Fluid Mechanics* **76**: pp. 457-480.

Parker, S.C. 1985. Predictive Modeling of Site Settlement Systems using Multivariate Logistics. In: Carr C. (ed.). *For Concordance in Archaeological Analysis*. Westport Publishers, St. Louis. pp. 173-207.

Parker-Pearson, M. 2003. 'Food, identity and culture: an introduction and overview'. In: Parker-Pearson, M. (ed.). *Food, Culture and Identity in the Neolithic and Early Bronze Age*. Oxford (BAR International Series **1117**).

Pascua, M. 1991. Ozette: Where whalers were chiefs and songs prized possessions. *National Geographic* **180**(4): pp. 38-54.

Paul, D.B. 1987. The Nine lives of discredited data. *The Sciences.* May Edition.

Pedersen, L. 1995. 7000 years of fishing. In: Fischer, A. (ed.). *Man and Sea in the Mesolithic.* Oxbow Mongraph **5**. Oxford. pp.75-86.

Pedersen, L., Fischer, A., and Aaby, A., 1997. *The Danish Storebaelt since the Ice Age – man, sea and forest.* Copenhagen: A/S Storebaelt Fixed Link.

Peeters, H., Murphy, P.L. and Flemming, N. 2009. *North Sea Prehistory Research and Management Framework 2009* Amersfoort: NSPRMF.

Pelejero, C., Kienast, M., Wang, L. and Grimalt, J.O. 1999. The flooding of Sundaland during the last deglaciation: imprints in hemipelagic sediments from the southern South China Sea. *Earth and Planetary Science Letters*. **171** (4): pp. 661-671.

Peltier, W.R., 1994. Ice-Age paleotopography, *Science*, **265**: pp. 195–201.

Peltier, W.R., Shennan, I., Drummond, R., and Horton, B. 2002. On the postglacial isostatic adjustment of the British Isles and the shallow viscoelastic structure of the Earth. *Geophysical Journal International* **148**(3): pp. 443-75.

Peltier, W.R. 2004. Global Glacial Isostasy and the Surface of the Ice-Age Earth: The ICE-5G (VM2) Model and GRACE. *Ann. Rev. Earth and Planet. Sci.,* **32**: pp. 111-149.

Peltier, W.R. 2005. On the hemispheric origins of meltwater pulse 1a. *Quaternary Science Reviews* **24**: pp. 1655-1671.

Pequart, M. and Pequart, S.J. 1954*. Hodic. Deuxieme Station – Necrople du Mesolithique Cotier Armoricain*. Antwerpen: De Sikkel.

Perez-Arlucea, M. and Smith, N.D. 1999. Depositional patterns following the 1870s avulsion of the Saskatchewan River (Cumberland Marshes, Saskatchewan, Canada). *Journal of Sedimentary Research*, **69**: pp. 62-73.

Peyton, L., Bottjer, R. and Partyka, G. 1998. Interpretation of incised valleys using new 3-D seismic techniques; a case history using spectral decomposition and coherency. *The Leading Edge*. **17:** pp. 1294-1298.

PGS 2004 *Data Library - Northwest Europe - Southern North Sea - MC3D Q44-99 SILVERPIT*, http://www.pgs.com/PDFTemp/PDF420137796.pdf. Accessed 16/04/2010.

Pickard, C., 2002. *Fishing in Mesolithic Europe.* Unpublished PhD thesis: University of Edinburgh.

Pickard, C. and Bonsall, C. 2004. Deep-sea fishing in the European Mesolithic: fact of fantasy ? *European Journal of Archaeology.* **7**(3) pp. 273–290.

Plets, R., Dix, J., Bastos, A. and Best, A. 2007. Characterization of buried inundated peat on seismic (Chirp) data, inferred from core information. *Archaeological Prospection,* **14** (4). pp. 261-272.

Post, K. 2000. Everzwijnjagers?. *Cranium*, **17**(1): pp. 13-14.

Posamentier, H.W. 2000. Seismic stratigraphy into the next millennium; a focus on 3D seismic data. *American Association of Petroleum Geologists Annual Conference*, New Orleans, LA, 16–19 April, 2000, A118.

Posamentier, H.W. 2005. Application of 3D seismic visualisation techniques for seismic stratigraphy, seismic geomorphology and depositional systems analysis: examples from fluvial to deep-marine depositional environments. In: Dore, A.G. and Vining, B.A. (eds.) *North-West Europe and Global Perspectives: Proceedings of the 6th Petroleum Geology Conference*. Geological Society of London. pp. 1565-1576.

Praeg, D. 1997. Buried Fluvial Channels: 3D-Seismic Geomorphology. In: Davies, T.A., Bell, T., Cooper, A.K., Josenhans, H., Polyak, L., Solheim, A., Stoker, M.S. and Stravers, J.A. (eds.) *.Glaciated Continental Margins: An Atlas of Acoustic Images*. Chapman and Hall, London. pp. 162-163.

Praeg, D. 2003. Seismic imaging of mid-Pleistocene tunnel-valleys in the North Sea Basin - high resolution from low frequencies. *Journal of Applied Geophysics* **53**: pp. 273-298.

Price, T.D. 1978. Mesolithic settlement systems in the Netherlands. In. Mellars, P. (ed.). *The Early Postglacial Settlement of North Europe. An Ecological Perspective*. pp 81-113 Duckworth. London.

Price, T.D. 1980. Regional Approaches to Human Adaptation in the Mesolithic of the North European Plain. In: Gramsch, P. *Mesolithikum in Europa*. Veroffenlichungen des Museaums fur Ur und Fruhgeschicte 14-15 Potsdam.

Price, T.D. 1985. Affluent foragers of Mesolithic southern Scandinavia. In: Price, T.D., and Brown, J.A. (eds.). *Prehistoric Hunter-gatherers: The Emergence of Cultural Complexity.* Academic Press, Orlando. pp. 341–363.

Pryor, F. 2004. *Britain BC: Life in Britain and Ireland before the Romans*, Harper Perennial. London.

Radley, J. and Mellars, P. 1964. A Mesolithic structure at Deepcar, Yorkshire and the Affinities of its associated Flint Industries. *Proceedings of the Prehistoric Society* **30**: pp. 1-24.

Reid, C. 1913. *Submerged Forests*. Oxford

Reidhead Van, A. 1980. "The economics of subsistence change: Test of an optimization model," In: Earle T.K. and Christenson A.L. *Modeling change in prehistoric subsistence economies.* Academic Press. New York. pp.141-86.

Renfrew, C. and Bahn, P. 2000. *Archaeology: Theories, Methods and Practice.* London: Thames and Hudson.

Reynier, M.J. 1998. Early Mesolithic settlement in England and Wales: some preliminary observations. In: Ashton, N., Healy, F.and Pettitt, P. (eds.), *Stone Age Archaeology. Essays in Honour of John Wymer*. Oxbow Monograph **102**; Lithic Studies Society Occasional Paper **6**,: pp. 174–84.

Reynier, M, 2000. Thatcham revisited: spatial and stratigraphic analysis of two subassemblages from Site III and its implications for Early Mesolithic typo-chronology in Britain. In. Young R. (ed.) *Mesolithic lifeways: current research from Britain and Ireland.* Leicester University Archaeological Monograph **7.** Leicester. pp. 33–46.

Reyneir, M. 2005. *Early Mesolithic Britain: Origins, development and directions.* BAR British Series **355**. Archaeopress. Oxford.

Reynolds, R.G.D. 1976. Linear Settlement Systems on the Upper Grijalva River: the application of a Markovian Model. In: Flannery, K. (ed.) *The Early Mesoamerican Village*. Academic Press, New York. pp. 180-194.

Richards, M.P. and Mellars, P.A. 1998. Stable isotopes and the seasonality of the Oronsay middens. *Antiquity* **72**: pp. 178-184.

Robein, E. 2003. *Velocities, Time-imaging and Depth-imaging in Reflection Seismics: Principles and Methods*. EAGE Publications

Roberts, A.J., Barton, R.N.E. and Evans, J. 1998. 'Early Mesolithic mastic radiocarbon dating and analysis of organic residues from Thatcham III, Star Carr and Lackford Heath'. In: Ashton, N.M., Healy, F. and Pettit, P.B. (eds.) *Stone Age Archaeology: Essays in Honour of John Wymer*, Lithic Studies. Oxbow Monograph **102**. Occasional Paper **6**.

Rokoengen, K., Lofaldli, M., Rise, L., Lqken,T. and Carlsen, R. 1982. Description and dating of a submerged beach in the northern North Sea. *Marine Geology***, 50,** M21-M28.

Rosgen, D.L. 1994. A classification of natural rivers. *Catena.* **22**(3): pp. 169-199.

Rowley-Conwy, P. 1983. Sedentary hunters: the Ertebølle example. In: Bailey, G. (ed.), *Hunter gatherer Economy in Prehistory: A European Perspective.* Cambridge University Press, Cambridge. pp. 111–126.

Rowley-Conwy, P. 1987. Animal bones in Mesolithic studies: recent progress and hopes for the future. In: Rowley-Conwy, P., Zvelebil, M. and Blankholm, H.P. *Mesolithic north-west Europe: recent trends*. Sheffield. pp.74-89.

Rowley-Conwy, P., 1995. Mesolithic settlement patterns: new zoological evidence from the Vale of Pickering, Yorkshire. University of Durham and University of Newcastle Upon Tyne Archaeological Reports 1994. pp. 1–6.

Salomonsen, I., and Jensen, K.A. 1994. Quaternary erosional surfaces in the Danish North Sea. *Boreas* **23**: pp. 244-253.

Sathiamurthy, E. and Voris, H. 2006. Maps of Holocene Sea Level Transgression and Submerged Lakes on the Sunda Shelf. *The Natural History Journal of Chulalongkorn University,* Supplement **2**: pp. 1-43.

Schiffer, M.B., Findlow, F.J. and Ericson, J.E. (eds.) 1980. *Catchment Analysis: Essays on Prehistoric resource space.* Anthropology UCLA. Vol 10.

Schock S.G. 2004. Remote Estimates of Physical and Acoustic Sediment Properties in the South China Sea Using Chrip Sonar Data and the Biot Model. *IEEE Journal of Oceanic Engineering*, **29** (4), pp 1218 - 1230

Schulting, R.J. and Wysocki, M. 2002. The Mesolithic human skeletal collection from Avelines' Hole: A preliminary note. *Proceedings of the University of Bristol Spelaeological Society* **22:** pp. 255-68.

Schulting, R.J. and Richards, M.P. 2000. Mesolithic subsistence and seasonality: the use of stable isotopes. In: Young, R. (ed.) *Mesolithic Lifeways: Current Research from Britain and Ireland*. Leicester, University of Leicester, Leicester Archaeology Monographs **7**. pp. 55-64.

Schulting, R.J. and Richards, M.P. 2001. Dating Women and Becoming Farmers: New Palaeodietary and AMS Dating Evidence from the Breton Mesolithic Cemeteries of Téviec and Hoëdic. *Journal of Anthropological Archaeology* **20**(3): pp. 314-344.

Schultz, P., 1999. *The Seismic Velocity Model as an Interpretation Asset, 1999 Distinguished Instructor Short Course, Distinguished Instructor Series No. 2*. SEG (Society of Exploration Geophysicists) Publications.

Sebastian, L. and Judge, W.J. (eds) 1988. *Quantifying the present and predicting the past: Theory, method, and application of archaeological predictive modeling*. U.S. Government Printing Office, Washington, D.C.

Shennan, I. 1986. Flandrian sea-level changes in the Fenland, II. Tendencies of sea-level movement, altitudinal changes and local and regional factors. *Journal of Quaternary Science*, **1**: pp. 155-179.

Shennan, I. 1989. Holocene crustal movements and sea-level changes in Great Britain. *Journal of Quaternary Science*, **4**: pp. 77 -89.

Shennan, I., Lambeck, K., Flather, R., Horton, B., McArthur, J., Innes, J., Lloyd, J., Rutherford, M. and Wingfield, R. 2000. Modelling western North Sea palaeogeographies and tidal changes during the Holocene .In: Shennan, I. and Andrews, J. (eds.) *Holocene Land-Ocean Interaction and Environmental Change around the North Sea*. Geological Society, London, Special Publication **166**: pp. 299-319.

Shennan, I., and Horton, B. 2002. Holocene land and sea-level changes in Great Britain. *Journal of Quaternary Science* **17** (5-6): pp. 511-526.

Shennan, I., Coulthard, T. Flather, R., Horton, B., Macklin, M., Rees J. and Wright M. 2003. Integration of shelf evolution and river basin models to simulate Holocene sediment dynamics of the Humber Estuary during periods of sea-level change and variations in catchment sediment supply. *Science of the Total Environment*. **314-316**: pp. 737-754.

Sherrif, R.E. 1977. Limitations on resolution of seismic reflections and geologic detail deriveable from them. In: Payton C. E., (ed.) *Seismic Stratigraphy - Applications to hydrocarbon Exploration*. Memoir of the American Association of Petroleum Geologists, Tulsa.

Shreve,. R.L. 1967. Infinite topologically random channel networks, *Journal of Geology* **75**. pp. 178–186.

Shumway G. 1960. Sound Speed and Absorption Studies of Marine Sediments by a resonance method. *Geophysics*, **20** (2), PP 451-467

Silberbauer, G.B. 1996. A sense of place. In: Burch, S.E and Ellanna, L.J. *Key Issues in Hunter-Gatherer Research.* BERG. Washington.

Simmons, I.G. 1996. The Environmental Impact of Later Mesolithic Cultures. Edinburgh: Edinburgh University Press.

Smith, C. 1992. *Late Stone Age Hunters of the British Isles*. Routlege Publishers.

Soluri E.A. and Woodson V.A. 1990 World Vector Shoreline. *International Hydrographic Review,* **LXVII**(1).

Song, Q., Gordon, A.L., Visbeck, M. 2004. Spreading of the Indonesian Throughflow in the Indian Ocean. *Journal of Physical Oceanography*. **34**: pp.772-792.

Spikens, P. 1999. *Mesolithic Northern England: Environment, Population and Settlement*, BAR British Series **283**. Archaeopress. Oxford.

Spikens, P. and Engen, M. 2007. 'A Needle in a Haystack ?': Perspectives on Prospection For Submerged Mesolithic Sites. In: Waddington, C. and Pedersen, K. *Mesolithic Studies in the North Sea Basin and Beyond: Proceedings of a Conference held at Newcastle in 2003.* Oxbow Books. Oxford.

Spikens, P. 2008. Mesolithic Europe: Glimpses of Another World. In: Bailey, G. and Spikens, P. (eds.) *Mesolithic Europe.* Cambridge University Press.

Stančič, Z. and Kvamme, K. 1999. Settlement Patterns modeling through Boolean overlays of social and Environmental Variables . In: Barcelo, J., Briz, I., Vila, A. Barca, J., Briz, I., Villa, A. (eds.), *New technique for old times,* Oxford: Archaeopress.

Stanèiè, Z., Veljanovski, T., Oštir, K. and Podobnikar, T. 2001. Archaeological predictive modelling for highway construction planning. In: Stanèiè, Z. and Veljanovski, T. (eds.), *Computing Archaeology for Understanding the Past*, CAA2000 Proceedings, Archaeopress, BAR International Series.

Steffens, G.S., Shipp, R.C., Prather, B.E., Nott, J.L., Gibson, J.L. and Winker, C.D., 2004. The use of near-seafloor 3D seismic data in deepwater exploration and production. In: Davies, R.J, Cartwright, J.A., Stewart, S.A, Lappin, M. and Underhill, J.R. (eds.), *3D seismic Technology: Application to the Exploration of Sedimentary Basins*. Geological Society of London Memoirs, **29**: pp. 35-43.

Stoker, M.S. and Long D. 1984. A relict ice-scoured erosion surface in the central North Sea. *Marine Geology*, **61**: pp 85-93.

Stoker, M.S., Long, D,and Fyfe, J.A. 1985. *A revised Quaternary stratigraphy for the central North Sea.* British Geological Survey Report **17**. HMSO: London.

Strahler, A.N. 1952. Dynamic basis of geomorphology. *Geological Society of America Bulletin*, **63**: pp. 923–938.

Strahler, A.H. and Strahler, A.N. 2000. *Modern Physical Geography* (4th Edition). Wiley. New York.

Street, M. 1989. *Jager und Schamanen, Bedburg-Konigshoven ein Wohnplatz am Niederrhein vor 10000 Jahren*. Mainz: Verlag der Romisch-Geranishce Zentralmuseums.

Stright, M.J. 1986. "Evaluation of Archaeological Site Potential on the Gulf of Mexico Outer Continental Shelf Using High-Resolution Seismic Data." *Geophysics* **51**(3): pp. 605-622.

Stright, M.J., Lear, E.M. and Bennett. J.F. 1999. *Spatial data analysis of artifacts redeposited by coastal erosion: a case study of McFaddin Beach*, Texas. U.S Department of the Interior, Minerals Management Service. OCS Study MMS 99-0068.

Stringer, C. 2006. *Homo Britannicus*. London: Penguin.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van der Plicht, J. and Spurk, M. 1998. INTCAL98 Radiocarbon Age Calibration, 24000-0 cal BP *Radiocarbon* **40**(3): pp. 1041-1083.

Suarez, Y., Marfurt, K. J. and Falk, M. 2008. *Seismic attribute-assisted interpretation of channel geometries and infill lithology: A case study of Anadarko Basin Red Fork channels*: 78th Annual International Meeting, SEG, Expanded Abstracts: pp. 963–967.

Thomson, K. and Gaffney, V.L. 2007. 3D Sesimic Reflection Data, Associated Technologies and the Development of the Project Methodology. In: Gaffney, V., Thomson, K. and Fitch, S. (eds.) 2007. *Mapping Doggerland: The Mesolithic Landscapes of the Southern North Sea.* Archaeopress. Oxford.

Tobon, M.C. 2002. *Side Scan Survey Offshore of the Big Bend: An Exercise in Ground-truthing*. Program in Underwater Archaeology Research Reports No. **18**. Florida State University.

Törnqvist, T.E. 1993. Holocene alteration of meandering and anastomosing fluvial systems in the Rhine-Meuse delta (Central Netherlands) controlled by sea-level rise and subsoil erodibility. *Journal of Sedimentary Petrology* **63**: pp. 683-693.

Van Dalfsen, W. Doornenbal, J.C., Dortland, S. and Gunnink, J.L. 2006, A comprehensive seismic velocity model for the Netherlands based on lithostratigraphic layers. *Netherlands Journal of Geosciences,* **85** (4), 277-292.

Van Veen, F.R. 1975. Geology of the Leman Gas Field In: Woodland, A.W. (ed.) 1975. *Petroleum and the Continental Shelf of North- West Europe.* 1, *Geology.* Applied Science Publishers, Barking, Essex.

Velegrakis, A.F., Dix, J.K. and Collins, M.B. 1999. Late Quaternary evolution of the upper reaches of the Solent River, Southern England, based upon marine geophysical evidence. *Journal of the Geological Society, London*. **156**: pp. 73-87.

Verhart, L. 1995. Fishing for the Mesolithic. The North Sea: a submerged Mesolithic Landscape. In. Fischer, A. (ed.) *Man and Sea in the Mesolithic*, Oxbow Monograph **53**. Oxford.

Verhart, L.B.M. 2004. The implications of prehistoric finds on and off the Dutch coast. *In* Flemming, N.C. (ed.) *Submarine Prehistoric Archaeology of the North Sea*. CBA research Report. **141**. York: Council for British Archaeology. pp. 57-64.

Verhart, L. 2005. A drowned land: Mesolithic from the North Sea floor. In: Louwe Kooijmans, L.P. and Broeke, P.W., Fokkens van den, H. and Gijn, A.L. (eds.) 2005. *The Prehistory of the Netherlands*. Amsterdam: Amsterdam University Press.

Verhart, L. 2008. New Developments in the Study of the Mesolithic of the Low Countries. In: Bailey, G. and Spikens, P. (eds.) *Mesolithic Europe*. Cambridge University Press.

Verjux, C. 2003. The function of the Mesolithic sites in the Paris basin (France). In: Larsson, L., Kindgren, H., Knutsson, K., Loeffler, D. and Akerlund, A. (eds.) *Mesolithic on the Move: Papers presented at the Sixth International Conference on the Mesolithic in Europe, Stockholm 2000*. Oxbow Books.

Von Thünen, J.H. 1966. *Isolated state; an English edition of Der isolierte Staat*. Translated by Wartenberg, C.H. (ed.). Oxford, New York: Pergamon Press.

Voris, H.K. 2000. Maps of Pleistocene sea levels in Southeast Asia: shorelines, river systems and time durations. *Journal of Biogeography* **27**: pp. 1153-1167.

Waddington, C. 1999. *A Landscape Archaeological Study of the Mesolithic-Neolithic in the Milfield Basin, Northumberland*. Oxford, Archaeopress British Archaeological Reports British Series **291**

Waddington, C., Bayliss, A., Bailey, G., Boomer, I., Milner, N., Pedersen K. and Shiel R. 2003. A Mesolithic coastal site at Howick, Northumberland. *Antiquity*. **77**: pp. 295.

Waddington, C., and Pedersen, K. (eds.). 2007. *Mesolithic Studies In The North Sea Basin And Beyond: Proceedings of a Conference Held at Newcastle in 2003*. Oxbow Books Oxford.

Waddington, C. 2007. *Mesolithic Settlement in the North Sea Basin: A Case Study from Howick, North-East England*. Oxbow Books. Oxford.

Walls, J.D., Taner, T.M., Taylor, G., Smith, M., Carr, M., Derzhi, N., Drummond, J. MucGuire, D., Morris, S., Bregar, J. and Lakings, J. 2002. Seismic reservoir characterization of a U.S. Midcontinent fluvial system using rock physics, poststack seismic attributes, and neural networks *The Leading Edge* **21**: pp. 428-436.

Ward, I., Larcombe, P., and Lillie, M. 2006. The dating of Doggerland - post-glacial geochronology of the southern North Sea. *Environmental Archaeology* **11** (2): pp. 207-218.

Ward, I., and Larcombe, P. 2008. Determining the preservation rating of submerged archaeology in the postglacial southern North Sea: a first-order geomorphological approach. *Environmental Archaeology* **13**(1): pp. 59-83

Warren, G. 2005. *Mesolithic lives in Scotland*. Stroud: Tempus.

Warren, R.E. 1990. Predictive modelling of archaeological site location: a case study in the Midwest. In Interpreting Space: GIS and archaeology, edited by Allen, Green and Zubrow. Taylor and Francis Ltd., London. pp. 201-215.

Westcott, S. 1996. *The Grey Seals of the West Country*. Stephen Westcott and Cornwall Wildlife Trust, Truro.

Wheatley, D. and Gillin, M. 2002. *Spatial technology and archaeology: the archaeological applications of GIS*. Taylor and Francis Ltd. London

Widness, M.B., 1982. Quantifying reolving power of seismic systems. *Geophysics*, **47**, pp 1160-1173

Willey, G.R. 1953. *"Prehistoric Settlement Patterns in the Virú Valley, Peru",* Bulletin **155**. Bureau of American Ethnology.

Woodman, P.C. 1985. *Excavations at Mount Sandel 1973-77. Northern Ireland* Archaeological Monographs **2**. Belfast: Her Majesty's Stationary Office.

Wymer, J.J. 1962. 'Excavations at the Maglemosian sites at Thatcham, Berkshire', *Proceedings of the Prehistoric Society*, **28**: pp.329-61.

Wymer, J.J. and Rose, J. 1976. *A long-blade industry from Sproughton, Suffolk and the date of the buried channel deposits at Sproughton*, Easty Anglian Archaeology. **3**: pp. 1–16.

Wymer, J. 1991. *Mesolithic Britain*. Princes Risborough: Shire Publications.

Yesner, D.R. 1985. Cultural boundaries and ecological frontiers in coastal regions: An example from the Alaska Peninsula. In: Green, S.W. and Perlman, S.M. (eds). *The archaeology of frontiers and boundaries.* Academic Press, New York.

Yilmaz, O. 1987. *Seismic data processing*: Society for Exploration Geophysicists.

Young, R. (ed.) 2000. *Mesolithic lifeways.* Leicester: Leicester University Press. Archaeology Monographs **7**.

Zagwijn, W.H. 1989. The Netherlands during the Tertiary and Quaternary: a case history of coastal lowlands evolution, *Geologie en Mijnbouw* **68**: pp. 107–121.

Zong, Y.and Horton, B. 1999. Diatom-based tidal level transfer function and its applications to palaeo-sea-level reconstruction. *Journal of Quarternary Science* **14**(2): pp. 153-167.

Zvelebil, M. 1981. *From Forager to Farmer in the Boreal Zone.* Two vols. Oxford: British Archaeological Reports, International Series, **115.**

Zvelebili, M. 1994. Plant Use in the Mesolithic and its Significance for the Transition to Farming in Europe. *Proceedings of the Prehistoric Society* **60:** pp. 35–74.