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Coastal Cells in Scotland: Cell 11 – Shetland

D L Ramsay & A H Brampton

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Research, Survey and Monitoring

REPORT

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The Scottish Office Agriculture, Environment and Fisheries Department, Historic Scotland and Scottish Natural Heritage.

THE SCOTTISH OFFICE   HISTORIC SCOTLAND   SCOTTISH NATURAL HERITAGE

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Note: *Due to their size, the maps in Appendix 2 have not been reproduced within this report, but are available for inspection, by prior arrangement, at the Earth Science Group, Advisory Services, Scottish Natural Heritage, 2 Anderson Place, Edinburgh EH6 5NP.*

Summary

This report reviews the coastline of Cell 11 which encompasses the coastline of Shetland. It describes the various coastal characteristics and processes which affect the regime of this particular stretch of shoreline. The report includes a description of the major coastal features, processes, and defences along with other aspects of beach development. The stretches of coastline, which for coastal management purposes, can be treated as independent or semi-dependent cells are also identified.

The study was carried out for Scottish Natural Heritage, Scottish Office Agriculture, Environment and Fisheries Department and Historic Scotland by the Coastal Group at HR Wallingford. The contract was administered by Dr George Lees of Scottish Natural Heritage. For further details of the study please contact Mr Douglas Ramsay or Dr Alan Brampton of the Coastal Group at HR Wallingford.

Note

This contract was undertaken prior to the establishment of The Scottish Executive. The report therefore contains references to The Scottish Office and The Secretary of State for Scotland. The following changes therefore apply and should be borne in mind when reading the report.

Previous terminology	*Present*
The Secretary of State for Scotland	The First Minister
The Scottish Office Agriculture, Environment and Fisheries Department	The Scottish Executive Rural Affairs Department

1 Introduction

1.1 General

In January 1996, HR Wallingford was commissioned by Scottish Natural Heritage (SNH), the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) and Historic Scotland (HS) to extend an existing study, (HR Wallingford, 1997) to define Coastal Cells and Sub-cells around the coastline of Scotland. This report, which reviews the coastline of Cell 11 which covers the coastline of Shetland, is one of a series of 11 reports covering the entire coastline of mainland Scotland, the Western Isles, Orkney and Shetland. The study concentrates on identifying and describing the various natural and man-made characteristics and processes which affect the behaviour of this particular stretch of coastline. The report includes a description of the dominant hydraulic processes, areas of erosion and accretion, coastal defences and various other aspects of the coastal regime. The aim of the report is to provide an overall understanding of the character and processes occurring within each sub-cell to allow as full an appreciation as is presently possible of the coastal regime on a macro scale.

1.2 Terms of reference

The terms of reference for this study were detailed by Scottish Natural Heritage in Annex A of their Project Specification. The aims are to provide:

(i) a basic description of coastal cells and their significance,

(ii) maps of each cell showing the location and boundaries of all sub-cells contained therein and the nature of the cell boundaries,

(iii) a map of each sub-cell showing the general direction(s) of littoral drift therein and known areas of erosion and accretion,

(iv) a map of each sub-cell showing the location of all sites designated for their nature conservation interest,

(v) a map of each sub-cell showing the location of sites designated for their historical or archaeological interest,

(vi) a map of each sub-cell showing the location of all principal coastal protection works and beach monitoring schemes,

(vii) descriptions for each sub-cell of the following characteristics and processes:

- geology and geomorphology
- wave and tidal regime
- areas of erosion and accretion and, where information exists, details of any rates of change
- assessment of existing erosion problems
- a summary of the relevance or implications of the littoral processes identified to sites of nature conservation interest
- a summary of the susceptibility of the historical and archaeological sites to coastal erosion

- existing coastal protection and management measures (including dredging and spoil disposal)
- present monitoring arrangements
- assessment of sensitivities of sites to climatic change and sea level rise.

1.3 Outline of report

A general introduction to the concept of coastal cells, and how the concept has been applied to the coastline of Scotland is provided in Chapter 2. Chapter 3 provides some general background information on the coastal environment of Scotland in the context of coastal cells. Chapter 4 provides reference to data sources of relevance to coastal management in Cell 11. Chapter 5 forms the main body of the report. A brief description of Cell 11 detailing the cell boundaries, a description of its character and the processes occurring there is given. An assessment of climatic change, sea level rise, and the likely effects on the coastline of Cell 11 is given in Chapter 6, with Chapter 7 listing the references used. A listing of Sites of Special Scientific Interest (SSSI), the locations of noted historical and archaeological sites, useful addresses and glossary are contained within the appendices of this report.

2 Coastal cells

2.1 Coastal cells

The concept of Coastal Cells was introduced in an initial document identifying the main cells around the coastline of Scotland, (HR Wallingford, 1997), and in a similar document for the coastline of England and Wales, (HR Wallingford, 1993a). The description below summarises the significance and importance of such cells in managing the coastline with regard to the naturally occurring processes acting upon it.

The processes which shape and alter a coastline show no respect for administrative boundaries. Coastal defences installed by one local authority have, at some sites in the UK, contributed to erosion along frontages under the care of an adjacent authority. These difficulties can be avoided by recognising the natural divisions of a coastline, often called coastal "cells". Where the main concern in managing a shoreline is to defend against erosion or flooding, then the most useful definition of a cell is based on a consideration of the longshore drift of beach material (sand and shingle). This is because most cases of severe coastal erosion are caused by interruptions to the natural longshore transport of sediment.

A recent study of the coastline of England and Wales, (HR Wallingford, 1993a), resulted in its suggested division into 11 main cells, each of which was further divided into sub-cells. An ideal cell would be entirely self-contained from a sediment transport viewpoint, i.e. there would be no nett import or export of beach material. Then, although coastal defence works could affect the whole cell by interrupting the longshore drift, they cannot affect beaches in other cells. Once established, these cells (and sub-cells) have proved to be a useful basis for shoreline management purposes. In England, the Ministry of Agriculture, Fisheries and Food (MAFF) have introduced Shoreline Management Plans; these are drawn up to provide a strategic basis for planning future coastal defences. Apart from considering aspects such as waves, tidal levels and coastal erosion/accretion, these Plans consider wider issues. Typically these include land use, ecological and geological conservation, tourism and recreation etc. As a consequence, in England and Wales, these plans provide a useful input into wider Coastal Zone Management initiatives. Each Plan is normally carried out for one or more sub-cells as defined above. An initial study has just been completed into defining coastal cells around the coastline of mainland Scotland, Orkney, Shetland and the Western Isles, (HR Wallingford, 1997).

On rocky coastlines, like of those of Shetland, where sediment is sparse, and beaches are often confined to deeply indented bays, then "cells" are often small and numerous. It becomes impractical in such areas to draw up a management plan for each cell; as a result it is sensible to group a number of these small bays together, to form a more convenient "cell" for management purposes. Considerations other than just the alongshore transport of beach material are used to define cells in these situations. These include general orientation of the coastline and its hydraulic environment. Cell 11 has been defined in this manner.

Bearing the above description of cell boundaries in mind, the coast of Scotland has been divided up into 11 main "cells" as shown in Figure 1. These major cells not only reflect beach sediment units, but also divide the coast into regions where the geology, physical character and orientation are similar.

For the purposes of coastal defence management, however, these major cells may be rather large, and contain too many conservation organisations, local authorities etc. for a single group to manage. Within these major cells, therefore, a number of "sub-cells" have been defined, and the description of the coast in this report is arranged using these smaller units.

At many sites, the sediment transport around a headland or a large harbour only moves in one direction, and is often of small volume. Engineering works on the updrift side of such a feature may therefore have some impact on the downdrift coast, but such impacts may be small or totally insignificant. Interference with the beaches downdrift of such a "one-way" valve will not affect beaches updrift. We can regard such sub-cells as being "partly dependent", with the understanding that the cell boundary between them is not totally "sediment-tight". An idealised cell is shown in Figure 2.

The definitions of cells and sub-cells in this report are principally derived from the viewpoint of movement of sand and shingle along the beaches, and taking into account the likely consequences of interfering with that movement, i.e. sediment movement in the littoral zone, Figure 3. A particular difficulty arises, however, in estuaries, which are often 'sediment sinks' and hence suitable cell boundaries. For those interested in the biological aspects of an estuary, or the movements of cohesive sediments, this separation of the estuary into two cells is inconvenient. To avoid this, we have preferred to define cell, (and sub-cell) boundaries, around Scotland on the basis of 'drift divide' points (e.g. headlands). The inner portions of several major firths have then been defined as sub-cells.

Identification of such coastal cells is intended to help planners determine the length of coastline likely to be affected by coastal works in a particular area. It is hoped that this type of 'overview' will assist in the understanding of the coastal system as a whole and may lead to a more unified approach to the planning of coastal defences, and hence assist in wider Coastal Zone Management.

2.2 Coastal planning and development

In England and Wales, Shoreline Management Plans co-ordinated with other initiatives can provide useful information in informing decisions on statutory policies, for example in areas which face particular pressures such as in estuaries where competing usage is often experienced. An example, from England and Wales, of the interrelationship between some of these initiatives is shown in Figure 4. Local authorities are required to produce a structure and local plan which together provide the Development Plan for an area. The Development Plan provides the statutory framework within which development control decisions are made. Shoreline Management Plans should be integrated within the work of the local authority and can have an important role in informing development plan policy.

There are several documents available which highlight the Government policy on key issues affecting the coastal zone. Of most relevance to the coastline of Scotland is the recently published discussion document from the Scottish Office on *Scotland's Coast* (Scottish Office, 1996) and *National Planning Policy Guidelines (NPPG)13: Coastal Planning* (Scottish Office, 1997). Similar publications in England and Wales, despite being geared to the legislative framework in these countries, are also of use in highlighting the key issues affecting the Scottish coastline. Of particular note, in the context of this report, is the Department of Environment (DoE) publication on *Policy guidelines for the coast* (DoE, 1995) and the MAFF publication, *Shoreline Management Plans - A guide for coastal authorities* (MAFF, 1995a).

2.3 Coast protection legislation in Scotland

The new Unitary Authorities with a coastal frontage are known as coast protection authorities under the Coast Protection Act 1949 and have powers under the Act to undertake such coast protection works as they consider necessary to protect any land in their area. Where coast protection work proposed is not maintenance and repair, the coast protection authority is required to follow the procedures defined in the Act. This may lead to approval by the Secretary of State. Once a scheme is approved by the Secretary of State, government grants are available towards the eligible cost of the works at a rate dependant on the authority promoting the scheme. The grant level can vary from between 20% to 80% at present.

The seabed below the Mean Low Water Mark of Ordinary Spring Tides is owned by the Crown Estate *prima facie* in law. The Crown Estate also owns much of the foreshore between Mean High and Mean Low Water Springs but does not hold a title to the foreshore and ownership can be displaced by anyone who can show a title derived from a Crown Grant. As part of the process required to enable consideration of schemes for approval under the Coast Protection Act 1949, consultation with the Crown Estate Commissioners is required. Approval must be obtained from the Commissioners before any coastal defence works, or any works on Crown Estate property is carried out.

Planning permission will be required for all new coastal defence works above Mean Low Water Mark of Ordinary Spring Tides and for any associated works such as borrow pits. In addition, building warrants are normally required for the construction of all walls and structures over a certain height. The exceptions to this are where work is being conducted within harbour limits and are covered by the Harbour Act 1964; for maintenance work; and for emergency works. There are a number of other consents which may be required before coastal defence work can be undertaken. Some of these are detailed in the table below:

Table 1 Required consents for proposed coast protection works

Consent	Application
Planning Permission (TCPSA 1997)	• All new works above MLWS • Associated works such as borrow pits above MLWS
Coast Protection Authority (CPAu) consent (CPA 1949)	• All coast protection works other than those carried out by a CPAu in its own area • New works carried out by a CPAu in its own area require consent of SoS (Scotland)
FEPA Licence (FEPA 1985, part II)	• Licence required for all operations entailing construction or deposition on seabed below MHWS
Environmental Statement (ES) (EA 1988/1994)	• If Planning Authority considers significant environmental effects to a "sensitive location" [1] will result from proposed works, it can require an ES with planning application
Notice of Intent (WCA 1981 Sn28)	• If works are permitted development on an SSSI

Notes

[1] Indicative criteria for assessing the significance of such impacts are contained within the Environmental Assessment legislation referred to.

Abbreviations used:

- CPA 1949: Coast Protection Act 1949
- CPAu: Coast Protection Authority
- EA 1988/1994: Environmental Assessment (Scotland) Regulations as amended
- ES: Environmental Statement
- FEPA 1985: Food and Environment Protection Act 1985
- SoS: Secretary of State
- TCPSA 1997: Town and Countryside Planning (Scotland) Act 1997
- WCA: Wildlife and Countryside Act 1981

Details of the statutory designations, and consultees, of conservation, historical and archaeological sites are described in Section 3.6.

3 The marine environment

3.1 Introduction

This chapter provides a brief general introduction to the coastal environment of Scotland in the context of this report. For more detailed information the reader is referred to the recently published CIRIA manuals *The use of rock in coastal engineering* (CIRIA, 1991) and the *Beach management manual* (CIRIA, 1996).

3.2 Geology and geomorphology

Scotland is composed of a particularly wide range of different rock types, representing most periods of geological time. Sedimentary rocks (those formed by the consolidation and lithification of sediments deposited in different marine and non-marine environments), igneous rocks (those formed by the solidification of lava erupted on the surface of the land or of magma which consolidated within the earth's curst) and metamorphic rocks (those formed by the alteration or deformation of other rock types) are all well-represented around the coastline.

In geological terms, Scotland can be considered as being formed of five distinct units or divisions, each separated by a major fault or fracture in the Earth's crust:

- the north-west Highlands and Islands west of the Moine Thrust, composed of "ancient" Lewisian gneiss;
- the Northern Highlands between the Moine Thrust and the Great Glen Fault, composed of the eroded roots of the Caledonian Mountain Belt, consisting primarily of 1,000 Ma old metamorphosed sediments of the Moine;
- the Central Highlands between the Great Glen Fault and the Highland Boundary Fault, composed of 800 Ma old Dalradian sediments and intruded with granites now forming the Cairngorms and other mountains and hills;
- the Midland Valley, composed of sediments deposited in tropical seas 300 Ma ago, extensive lava fields of the Ochils and Clyde plateau and the volcanic rocks of Edinburgh and the Laws of Fife and East Lothian; and
- the Southern Uplands, composed of sediments deposited in the former Iapetus Ocean which, for over 100 Ma, separated Scotland and England.

The geological structure and the lithological variability exert a strong influence on the morphology of the coastline. However, it is the processes which have occurred over the last ca. 2 Ma (during the period known as the Quaternary) that have left a major impact on the coastline, in particular those during the last (Late Devensian) glaciation (ca. 26,000-10,000 years) and in the postglacial period or Holocene.

The last ice sheet, which reached a thickness of 1500 metres in places, advanced from the Highlands over the entire Scottish mainland and most of the islands. Ice extended off-shore and local ice-caps may have existed on the more remote island groups such as Shetland and the Western Isles. Sea level, world-wide, was up to 140 metres lower than it is today. This, and earlier ice sheets, extensively scoured and eroded the bedrock, particularly in the west where it carved out the fjords and sea lochs along lines of pre-existing geological weakness. By 13,000 years ago the ice sheet had melted, depositing a variable cover of drift off-shore in the process. On-shore the ice deposited a thick cover of till in the more eastern areas. Meltwater from the retreating ice also deposited glaciofluvial deposits in the major eastern valleys and coastal lowlands. As sea level rose during deglaciation, some of the glacial sediments in the off-shore zone were reworked and moved into the present coastal zone, and fresh material was eroded from the glacial deposits on the coast. It is the material derived from these glacial deposits which supplied the majority of the sediment for the sand and shingle beaches of the present coastline.

As the ice sheet melted, the loading it applied on the Earth's crust was removed, resulting in the land recovering, or rising, typically at rates of a few millimetres per year (known as isostatic uplift). Rates varied, however, being greater where the ice was formerly thickest and less where the ice had been thinner, as was the case, for instance, around the Northern and Western Isles. At the same time, melting of the ice sheets caused global sea level to rise (known as eustatic rise). Accordingly, the patterns of relative sea level change during and since the ice age have varied around the country depending upon each location's proximity to the centre of the former ice sheet.

When the ice first began to melt, between approximately 17,000 and 15,000 years ago, global or eustatic sea level rose, flooding over the continental shelf and engulfing many coastal areas. In some western areas, such as Jura and Arran, "raised" beaches were deposited on the coast at heights of up to 40m above present day high water mark. Thereafter, isostatic uplift gradually overtook eustatic rise causing a relative fall in sea levels around most of the country. This trend continued, with local variations, until around 8,000-9,000 years ago, bringing sea level down to around or below present day levels in most areas. At that time, eustatic rise once more overtook isostatic uplift and relative sea level rose again (known as the Postglacial Transgression) to attain a maximum height relative to the land, in most areas, around 5-6,000 years ago.

Since that time eustatic rise has tailed off and so isostatic uplift has caused, in general, a gradual fall in relative sea level of around 1-2 millimetres per year in Scotland, though recent studies suggest that changes in sea level related to global climate change may now be counteracting this. Moreover, in areas remote from the centre of the main Scottish ice cap, such as the Northern and Western Isles, eustatic rise in sea level has continued to outpace isostatic uplift and so gradual submergence has dominated in these areas in recent millennia, rather than emergence.

3.3 Hydraulic processes

In understanding the recent (and past) evolution of the coastline a knowledge of the prevailing tidal levels, currents, wave and swell conditions is necessary.

<u>Tidal levels</u>
Tidal levels experienced around the Scottish coastline are generally made up of two components, an astronomical component and a residual component due to weather effects. The main tidal driving forces are the "astronomical forces"'- the major contribution being due to the relative motions of the Earth, Moon and Sun. The differential gravitational effects over the surface of the oceans cause tides with well defined "semi-diurnal" and "diurnal" periods (actually about 12.38 and 24.76 hours respectively).

In addition to the contribution to the tides which results from the earth's rotation, other periods are apparent in the fluctuation of tidal levels, for example the fortnightly spring-neap cycle, corresponding to the half period of the lunar cycle. Due to the slight ellipticity of the earth's orbit around the sun, there is also an annual variation of tidal effects. The solar tidal components are increased due to declinational effects giving rise to the equinoctal tides in September and March. Even longer variations can also be identified, such as that of approximately 18.6 years which corresponds to the changing angle between the axis of the earth and the plane of the moon's orbit.

Analysis of tidal measurements takes advantage of the knowledge of these precisely known periods, and uses a "harmonic" analysis of the measured data to derive information on the phase and magnitude of each tidal constituent, i.e. a component with a defined period. By analysis of the range (i.e. the vertical difference between high and low water levels), and the timing of the arrival of high/low waters, considerable light can be shed on the propagation of tides around the coast. All the tidal energy experienced around the coastline of Scotland stems from the Atlantic and were it not for the openings to the Atlantic, there would be no noticeable tide in the North Sea. Once the tidal energy reaches the shallow waters of the north-west European continental shelf, however, it becomes concentrated by both the reducing water depth and the converging land-masses. A large number of complex processes then occur, including reflections and complicated swirling motions around areas of little or no tidal range (so called *amphidromic points).*

Sufficient information to predict tides with reasonable accuracy can be gathered in as little as four weeks (a Spring-Neap tidal cycle) in most locations. However, longer periods of recording are necessary to accurately determine all the components. Some of the most influential components, or "harmonics", are normally presented in Tide Tables. It is possible to purchase software (a) to analyse tidal measurements, and/or (b) to use the resulting (or published) harmonics to make your own predictions of water levels. Yearly <u>predictions</u> of water levels are published in the Admiralty Tide Tables. The tide tables also tend to give levels relative to "Chart Datum" and the relationship between the particular "Chart Datum" and a more "universal" vertical datum, e.g. Ordnance Datum Newlyn (ODN) in the UK, must <u>always</u> be carefully established. For the design of coastal works, it is better to use information derived from analysis of <u>recorded</u> water levels (see below), related to a land-based vertical datum, e.g. ODN.

Actual water levels experienced around the coastline will vary from those predicted in the Admiralty Tide Tables. Generally speaking the differences between the levels of highest astronomical tide and, say, the largest predicted tide in any year is rather small (i.e. a few centimetres). In practice, this difference is unimportant, at least in Scotland, when compared with the difference between predicted and observed tidal levels due to weather effects. As a very simple example, a static depression with a pressure 38 millibars lower than average can produce an increase of 0.3m in tidal level above that predicted. Such static barometric effects, however, are usually less important than dynamic ones.

A rapidly changing weather pattern will often produce short period fluctuations in atmospheric pressure, which in turn produce fluctuations of a similar timescale in the tidal curve. A good example is provided by the passage of a series of squalls. As a result, undulations in tidal level are caused, with a typical period of a few minutes. These undulations are usually called 'seiches', and on the open coast they normally present no great problems, since the associated changes in water levels, velocities and accelerations are small. However, in enclosed or partly enclosed bodies of water such as harbours, bays or sea lochs the periodicity of the seiches can cause a resonance which amplifies their effect. This rarely occasions any distress to coastal defences but can cause problems to moored ships.

The most important meteorological effects which alter water levels are generally known as 'storm surges'. Such surges result from the effects of wind stress on the surface of the sea. In shallow seas, such as the North Sea, a strong wind can cause a noticeable rise in sea level within a few hours. As one result, tidal levels at the coast can be increased (at both high and low water) until the wind abates. If the wind suddenly drops and then reverses in direction, the excess water held in an area by the wind can then be released, usually as one or more long waves. If such waves are amplified by a narrowing estuary, they can attain a significant amplitude and if the resulting surge arrives at a coast at the same time as the high water of an astronomical tide, the nett result can be devastating.

In the North Sea, such effects can regularly produce a "residual", i.e. a difference between predicted and actual water levels of a metre or so. In severe events, a "surge" can be produced, i.e. a long wave-like disturbance which can add several metres to the tidal level, although fortunately not often at high tide. "Negative surges" can also occur, for example under an anti-cyclone, producing much lower levels than expected.

It is often the combination of a surge and a predicted high tide which causes flooding or damage along a coast. Both the height of surges, and the time of their arrival relative to (predicted) high water are very variable. A considerable amount of research into such events has been carried out, with the main objective of predicting extreme tidal levels. Such predictions are usually expressed in a probabilistic manner, using the idea of "return periods". For example the 100-year (return period) tidal level is that level expected to occur or be exceeded only once, on average, in each century.

For sites where there is insufficient measured data, it is necessary to use numerical modelling to predict such extreme levels (by interpolation from nearby sites), or to "hindcast" tidal levels that have occurred in the past. This latter task is important if information on a particular severe event is required, for example to analyse the causes of flooding or of damage to coastal structures.

Tidal currents

The tides occurring around the coastline of Scotland also result in significant tidal currents, even in areas where the tidal range is small, e.g. off the coast of Islay. Where the shape of the coast allows the tide to fill and empty a large area during each cycle (e.g. estuaries, tidal inlets), the effects of the currents often dominate the hydraulic and sedimentary regime of the area. Even on an open, wave dominated coastline, such currents have a variety of effects. They act together with the waves to transport sediment more efficiently, both on beaches and over the nearshore seabed. As a result of this capacity to transport sediment, the tide can produce shifting banks of sediment which affect coastal processes. The currents also interact with the waves, altering their character, especially where they are similar to the wave propagation speeds. Finally, although the currents tend to be roughly equal on flood and ebb in most places, the small asymmetries can be fundamentally important in a large number of ways, particularly in the transport of fine-grained sediments (muds and clays), together with any adsorbed pollutants, for example heavy metals. In terms of sediment transport in the nearshore zone, the direction and velocity of currents acting at High Water Level may be more important than higher current velocities acting at mid tide. Similarly the tidal residual (vectorial displacement over the period of one tidal cycle) may also be important in the transport of nearshore sediments, particularly in estuaries.

While tidal levels vary slowly in space, and can be represented by a single value for each location at a specified time, tidal currents are much more complex. Very substantial changes in speed and direction can occur over a few tens of metres. Also, currents can change significantly with depth. In the open sea, such changes are often modest, i.e. a gradual reduction in speed below the water surface, but maintaining a consistent direction. However, in shallow water close to a coast, in estuaries, and in the vicinity of structures, the situation is often much more complex. Indeed flows can be in very different, sometimes entirely opposing, directions at the surface and near the seabed.

Waves and swell

The action of waves on the coastline is normally the dominating process influencing the littoral regime. The main wave influence on much of the Scottish coastline is from wind generated waves. Such waves have periods in the range 1-25 seconds, but in Scottish coastal waters the important range is usually between 4 and 20 seconds. The size and period of waves which strike a coast depend on the wind speed, its duration and the 'fetch', that is the unobstructed distance over the sea surface that the wind has travelled. On open coasts where the fetch is very large but the wind blows for only a short period, the wave height is limited by the duration of the storm. Beyond a certain limit, the total fetch length becomes unimportant. Where fetch lengths are restricted, e.g. by offshore islands, a short storm may produce the largest potential waves and any increase in the duration will not cause extra wave growth. Such waves are described as "fetch limited".

On oceanic shorelines, including some of the Scottish coastline (especially the exposed west and north coast), the situation is usually more complicated. Where both the fetch and durations are extremely large waves then become 'fully developed' and their height depends solely on the wind speed. In such situations the wave period usually becomes quite large, and long period waves are able to travel great distances without suffering serious diminution. The arrival of "swell', defined as waves not generated by local and/or recent wind conditions, presents a difficulty in wave forecasting which it is only now becoming possible to overcome, using for example a global wave forecasting model.

Swell waves are of nearly constant period and direction (although the height of successive waves does vary). Swell can be measured easily and accurately gauged "by eye", but is difficult to predict numerically. In contrast, waves generated locally (i.e. over a few hundred kilometres, during a day or so) are much more variable in direction and period. These waves are more difficult to measure, or gauge accurately by eye, but much easier to forecast numerically.

As waves approach the shoreline they are altered as shallow water processes become important. Around much of the UK this starts to affect waves in water depths of around 20m (more off the north and west coasts of Scotland, where larger wave conditions are experienced). In shallow water the main processes in the transformation of waves are shoaling, depth-refraction, current refraction, seabed friction, wave breaking, diffraction and reflection. In general terms this results in a decrease in wave heights as they travel into shallow water but little change in wave period. Whereas offshore wave conditions vary gradually in space, inshore wave conditions are normally site-specific with considerable variation often experienced over relatively short distances. Similarly around the coastline of the UK, offshore wave conditions are experienced from every directional sector. However, the range of wave directions experienced in shallow water will be much smaller and some offshore wave directions may be unimportant.

For coastal engineering purposes, both offshore and inshore wave conditions are normally defined in terms of the significant wave height, H_s (which is the average height of the highest one third of the waves in a given sea state), the wave period, T_m (which is the time taken for two successive wave crests to pass the same point), and the wave direction, θ.

3.4 Littoral processes

The concept of coastal cells is concerned with sediment movements in the littoral zone (see Figure 3). The rate and direction of such movements are influenced not only by the prevailing hydraulic processes, such as swell and wind waves and tidal, wind and wave induced currents, but also by the bathymetry and the physical characteristics of the beach and seabed (e.g. sediment size).

On a sand or shingle beach, the influence of the natural processes, particularly the wave action, will result in the beach attempting to attain an equilibrium profile. This profile will normally vary depending on the incident conditions. For example there is often a distinct summer/winter cycle where storm wave action in winter months draws beach material further down the beach to below the low water mark resulting in a flatter beach slope. This material is then transported back up the beach during the summer (resulting in a steeper beach slope) during milder wave conditions. Where there is little long term change in the beach morphology the beach system is said to be in dynamic equilibrium. In general, drawdown of the beach occurs at a much quicker rate, e.g. over the period of a single storm, than beach build-up, which may take a number of months. Hence, beach material may appear to have been eroded when it may simply be removed due to a recent storm with there being insufficient time for the material to be moved back onto the upper beach.

Where waves break obliquely at the coast a longshore current will be created in the surf zone which, when acting with the stirring action of the waves, will result in the longshore transport of material. Littoral drift is a dominant influence in shaping the coastline and is the major cause of coastal erosion (or accretion) particularly where the dynamic equilibrium of the drift regime is altered in any way (either due to natural changes or due to other external influences, e.g. human). On most of Scotland's beaches, sediment will move in both directions along a beach due to waves from different directions. However, it is normally the nett sediment transport rate and direction which is of greatest importance. A nett transport of material may be evident at the coastline, e.g. where there is a build up against a harbour breakwater, or a groyne over a length of time (years). However, it is often difficult to determine the direction and magnitude of any littoral transport confidently, particularly around the coastline of Scotland where the magnitude and direction of wave conditions are variable. To do so normally requires the use of numerical models which predict longshore transport using a time series of wave data. In certain situations, other hydrodynamic processes can cause littoral drift, either adding to or opposing the drift caused by waves breaking obliquely to the beach contours. These processes include tidal currents and longshore variations in breaking wave height. The former can be important when currents are still strong at high (and low) water, especially on straight coastlines (e.g. north of Aberdeen). The latter process is well demonstrated by the shelter provided by an offshore island. This provides substantial spatial variations in wave height, leading to a strong drift from the more active areas into the sheltered water.

In addition to an understanding of sediment movements, a knowledge of the inputs and outputs of sediment into the littoral regime is required. This is known as the sediment budget. It is important to know whether there is any fresh source of beach material being input to the system, e.g. from fluvial sources, cliff erosion or offshore deposits, or whether existing material is being reworked by coastal erosion. Similarly knowledge of whether material is being lost completely from the beach system, e.g. offshore, or if it is moved by wind action into a dune system, or whether it is accreting on the beach, is also important.

To assess the possible impacts and requirements of future coastal protection works, and to understand the likely future evolution of the shoreline, a quantitative understanding of these littoral processes is required.

3.5 Coastal defence, monitoring and management

There are two main types of coastal defence - "Coast Protection" where engineering works are used to protect an eroding coastline from further erosion, and "Sea Defence" where works are provided to prevent flooding of the coastal hinterland due to extreme wave and/or tidal conditions. In assessing existing defences along a frontage there are three main criteria which need to be examined:

- the structural condition of the defence,
- its capacity to prevent overtopping or flooding,
- the impact of the defence on the surrounding littoral regime.

The standard of protection provided by a section of coastal defence depends on the margin of safety it provides against structural collapse or unacceptable high overtopping discharge for example, both of which are highly influenced by the level and condition of the beach in front of the defence. Each of these criteria are interrelated with structural failure a consequence of the hydraulic forces as well as structural and geotechnical aspects. Overtopping and flooding, as well as depending on the severity of storm conditions, is also a function of the crest level of the structure and cross-sectional profile. Similarly the condition of the beach in the locality of the defence is a function of the sediment supply, hydraulic conditions and also of the type and design of the structure.

Construction of coastal defences, either to prevent flooding or to control coastal erosion, can have a variety of effects on the coastline and the development of beaches. Linear structures built along a frontage can have various detrimental effects on a beach. For instance, structures constructed in front of eroding cliffs or links areas can prevent the contribution of fresh material to the beaches, with resulting sediment starvation of the coast downdrift, known as downdrift erosion. Where wave action interacts with a linear defence, wave reflections from the structure can lower the level of the beach in front of it, and hence allow greater wave attack on the structure itself.

Of greater impact on the littoral regime is the effect of interrupting or altering the longshore transport of beach material, e.g. by the construction of a harbour breakwater or construction of a groyne system. The long-term effects of either reducing or stopping all drift along a coastline, can be an increase in erosion at beaches further along the coast due to sediment starvation.

3.6 Natural and cultural heritage

There are a number of statutory and non-statutory forms of designations which are used to protect terrestrial sites with natural and cultural heritage value. Statutory designations, or areas which have some form of 'custodial' ownership, have mechanisms which protect them, to a limited extent, from certain development or harmful activities. There is also a wide range of conservation legislation protecting individual habitats and species which may affect future shoreline management. Further information on natural heritage sites can be obtained from Scottish Natural Heritage with information on cultural heritage sites from Historic Scotland.

The range of national and international designations afforded to the coastal areas of Scotland of direct relevance to shoreline management, the designating organisations, and a short description of each taken from the Scottish Office discussion paper, *Scotland's Coasts* (Scottish Office, 1996), are detailed below:

<u>Sites of Special Scientific Interest (SSSI)</u> <u>Scottish Natural Heritage</u>
Designated by SNH under the Wildlife and Countryside Act 1981 Section 28 to protect areas of important flora, fauna, geological or physiological features. Extensive parts of the coast are included within the SSSI network but the legislation only applies to land above MLWS.

SSSIs provide the basis for other national and international designations e.g.. NNRs and SACs. SNH requires to be consulted on developments, or notified of potentially damaging operations, which may affect the SSSI interest.

National Nature Reserves (NNR) — Scottish Natural Heritage

Declared by SNH under the National Parks and Access to the Countryside Act 1949 Section 16. NNRs are owned or leased by SNH or managed under agreement to protect and enhance their outstanding nature conservation interest. Public access may be controlled through bylaws. NNRs are also SSSIs, and some have coastal frontage or are offshore islands.

Marine Nature Reserves (MNR) — Scottish Natural Heritage

Provision is made in the Wildlife and Countryside Act 1981 Sections 36 and 37 to designate marine areas to conserve their marine flora and fauna. This is the only statutory designation which specifically relates to marine areas below the low water mark. Designation procedures involve extensive consultation and protection is by byelaws. There are currently no MNRs in Scotland but a voluntary Reserve operates at St Abb's Head in Berwickshire.

Local Nature Reserves (LNR) — Local Authorities/Scottish Natural Heritage

Section 21 of the National Parks and Access to the Countryside Act 1949, and Section 10 of the Local Government (Scotland) Planning Act 1982, give powers to local authorities in conjunction with SNH to establish Local Nature Reserves for their conservation and amenity value and for the public enjoyment of the countryside. They are controlled by byelaws. To date three coastal LNRs have been established in Scotland.

Special Areas of Conservation (SAC) — Scottish Office

SACs are to be designated under the 1992 EC Directive on the Conservation of Habitats and Species. The special interest of SACs must be strictly protected. SACs, together with SPAs classified under the EC Wild Birds Directive (see below), will form a European-wide network of sites known as Natura 2000. The main aim of the network is to maintain the relevant species and habitats in a favourable conservation status. Coastal and marine sites are among the areas which, following consultations, are being proposed to the European Commission for SAC designation.

Special Protection Areas (SPA) — Scottish Office

The 1979 EC Directive on the Conservation of Wild Birds requires special measures to be taken to protect wild birds and their habitats, including the designation by the Secretary of State of Special Protection Areas to safeguard vulnerable species and regularly occurring migratory birds. Scotland is particularly important for cliff-nesting seabirds, waders and wildfowl. SPAs are subject to the same strict protection of their special interest as SACs.

Ramsar sites — Scottish Office

The Ramsar Convention requires wetlands of international importance to be protected to safeguard wetland habitats and species including those which contain large numbers of wildfowl. Several coastal or marine areas are designated or proposed Ramsar sites. The Secretary of State, on the advice of SNH, designates Ramsar sites and the Government has decided that as a matter of policy these sites should be accorded the same strict protection as for SPAs and SACs.

National Scenic Areas (NSA) — Scottish Natural Heritage

National Scenic Areas were introduced by circular in 1980 (amended in 1985) to safeguard areas of outstanding landscape importance as identified by SNH (formerly CCS). Policies for protecting NSAs are set out in development plans and planning authorities are required to consult with SNH on specific categories of development. A number of NSAs incorporate part of the coast.

Natural Heritage Areas (NHA) — Scottish Natural Heritage

The Natural Heritage (Scotland) Act 1981 Section 6 makes provision for the designation of NHAs, although none has been introduced to date. These will cover extensive areas including the coast within which nature conservation, landscapes and cultural issues will be managed under a single integrated management plan which will be approved by the Secretary of State.

Areas of Great Landscape Value (AGLV) — Local Authorities

Under the provisions of Circular 2/1962, AGLVs are identified by local authorities in development plans with appropriate policies to protect areas of regional or local landscape importance. AGLVs vary in area and may include parts of the coast.

Environmentally Sensitive Areas (ESA) — Scottish Office (SOAEFD)

These are designated by the Secretary of State under the 1986 Agriculture Act to encourage landowners to manage their land to safeguard and enhance the nature conservation, landscape and cultural interest of the land for which a grant is available.

Marine Consultation Areas (MCA) — Scottish Natural Heritage

These are non-statutory areas introduced in 1986 where SNH wish to be consulted on developments, in particular fish farms, which are likely to have an impact on the marine environment. There are 29 sites within Scotland, most of which are on the West Coast or the Islands.

Regional Parks and Country Parks — Local Authorities

These are promoted by the local authorities under the provision of Section 48 of the Countryside (Scotland) Act 1967 to provide informal outdoor recreation and to protect local landscape and amenity for the enjoyment of the public. Country parks are relatively small areas used intensively for informal recreation. Regional parks are extensive areas where existing land use continues but also accommodates recreational activities. Some of these parks incorporate coastal areas.

RSPB Reserves — Royal Society for the Protection of Birds

Private reserves owned by the Royal Society for the Protection of Birds where the main interest is ornithology but where there are often other important conservation interests.

Scheduled Monuments — Historic Scotland

Ancient monuments surviving in both town and country are tangible reminders of Scotland's long history. Because of the evidence they can provide about Scotland's past many ancient monuments are given legal protection against deliberate or accidental damage or destruction by being "scheduled". A scheduled monument is a monument which the Secretary of State considers to be of national importance and has included in a set of records (known as the Schedule) maintained by him under the Ancient Monuments and Archaeological Areas Act 1979.

4 Cell 11 - Information sources

4.1 General

Information on the physical characteristics and coastal regime is available from a variety of sources and organisations. The purpose of this section is to provide general details on the availability of such information and of any data sources of relevance to shoreline management. Further, site specific information, particularly on littoral processes and coastal defences, is contained within each of the sub-cell sections.

The UK Digital Marine Atlas (UKDMAP) which was developed by the British Oceanographic Data Centre, Birkenhead, (BODC, 1991) provides a reference database of the marine environment for the whole of the UK. It provides general information on a wide range of subjects including geology, hydrography, conservation and ecology. A review of information relating to the natural environment, the current protected status of coastal and marine habitats, communities and species and activities is contained in *Coasts and Seas of the United Kingdom: Region 1: Shetland* (Barne et al, 1996).

Details of physical oceanographic and meteorological (metocean) data collected around the British Isles on behalf of the UK energy industry are summarised in a report by Metocean (1994). This includes details on organisations who have collected information on winds, waves, currents, water levels and other associated parameters. Further information sources of physical data are detailed in the following sections.

4.2 Geology and geomorphology

The geology of the Shetland Islands has been reviewed in detail in several studies, the most comprehensive being *British Regional Geology: Orkney and Shetland* (Mykura, 1976) and *Shetland: Localities of Geological and Geomorphological Importance* (Black, 1976). These reports references a large number of more detailed localised studies conducted within Shetland. The British Geological Survey has also produced a series of solid and drift geology maps the availability of which is detailed in Table 2.

Table 2 Available geological maps

Map No.	Map Name	Solid/Drift Geology	Scale
Special sheet	Northern Shetland	Solid/Drift	1:63,360
Special sheet	Western Shetland	Solid/Drift	1:63,360
Special sheet	Central Shetland	Solid/Drift	1:63,360
Special sheet	Southern Shetland	Solid/Drift	1:63,360

The Geological Conservation Review was a 12 year research programme initiated by the Nature Conservancy Council in 1977 to identify the key onshore earth science sites in Great Britain using available survey and research information. Site classification was completed in 1989 and the review is currently being published through a series of approximately 40 volumes, 14 of which are now available.

The geomorphology of the Shetland coast has been studied in detail in *The coastline of Scotland* (Steers, 1973) and *The beaches of Shetland* (Mather & Smith, 1974).

4.3 Bathymetry

The bathymetry around Shetland is illustrated in detail on the following Admiralty Charts:

Table 3 Available Admiralty Charts

Chart No.	Location	Scale
1119	Orkney & Shetland Islands, Fair Isle Chart	1:200,000
1233	Northern approaches to the Shetland Islands	1:500,000
1234	NW approaches to the Orkney Islands	1:200,000
3281	Shetland Islands - NW Sheet	1:75,000
3282	Shetland Islands - NE Sheet	1:75,000
3290	Lerwick Harbour	1:7,500
3291	Approaches to Lerwick Harbour	1:17,500
3292	Eastern approaches to Yell Sound, Colgrave Sound & Bluemill Sound	1:30,000
3293	Harbours in Yell and Unst	1:10,000
3294	Shetland Islands - Harbours in Southern Mainland	Various
3295	Harbours in the Shetland Islands	Various
3297	Sullom Voe	1:12,500
3298	Yell Sound	1:30,000

The charts are produced by the Hydrographic Office, Taunton, and also include information on tidal streams, tidal levels and other information of use to the navigation of sea vessels.

4.4 Wind data

There are a number of anemometer stations where winds have been recorded and the information passed to the Met Office which could be useful in estimating wave conditions around the Shetland Islands. At present the recorders at Sella Ness and Balta Sound are equipped with Semi-Automatic Meteorological Observing Systems (SAMOS) which produce wind statistics continuously for immediate archiving. The recorders at Lerwick and Sumburgh are equipped with Digital Anemograph Logging Equipment (DALE), which logs wind data onto magnetic tape, and which is sent to Bracknell for incorporation into the Climatological Data Bank. Information from the recorder on the Fair Isle may also be of some use. However, a graphical recorder is used there, which has to be hand-analysed to provide suitable data for archiving. A summary of the available wind data is provided in the following table:

Table 4 Cell 11 - Availability of wind data

Location	Period covered	Anemometer Type
Balta Sound	05/74 - Present	Analysed anemograph from SAWS/SAMOS/CDL station
Fair Isle	06/83 - Present	Data on Metform 6910
Lerwick	01/70 - Present	Digital Anemograph Logging Equipment (DALE)
Sella Ness	09/79 - Present	Analysed anemograph from SAWS/SAMOS/CDL station
Sumburgh	10/71 - Present	Digital Anemograph Logging Equipment (DALE)

4.5 Tidal data

The only A-class tidal gauge installation within this Cell is at Lerwick. A-class gauges are installed and maintained as part of a national network of tide-gauges organised by the Proudman Oceanographic Laboratory (POL) situated at Bidston, Merseyside. Long term measurements from these gauges have been analysed to produce "harmonic constants" from which predictions of tidal levels can be made for any desired time. Harmonic constants can be used to provide local tide predictions, either by POL or other organisations who have obtained the relevant computer programs to make such predictions. It should be realised, however, that the harmonic constants derived for these sites may not be as reliable as those from an A-class gauge. Tidal gauges were also installed for short periods of time at Balta Sound, Foula, Sumburgh and Fair Isle with the information held by BODC. Care must be taken in the Shetland Islands as Ordnance Datum is referred to a local datum and not to Ordnance Datum Newlyn.

Information on mean sea level can be obtained from the Permanent Service for Mean Sea Level (PSMSL) which is located at the Bidston Observatory in Birkenhead. This was set up in 1933 and is responsible for collecting monthly and annual mean values of sea level from approximately 1450 tide gauge stations around the world. The contents of the PSMSL data set are described in a report *Data holdings of the PSMSL* (Spencer & Woodworth, 1993) which can be obtained from the Bidston Observatory. Within Cell 11 mean sea level is recorded at Sullom Voe and at Lerwick.

Actual tidal levels, however, can and often do vary significantly from those predicted using harmonic analysis due to the influence of meteorological effects (surges) see Section 3.3. The UK Met Office Storm Warning Service operate a surge prediction model provided by POL. This has a 12km spatial resolution around the coast of the UK, and can provide information on surge conditions offshore of the Shetland Islands. To provide predictions at the coastline a more detailed numerical model would be required.

A number of studies have been conducted into extreme (surge) water level predictions (e.g. Graff, 1981; Woodworth, 1987; Coles & Tawn, 1990). The latest research into trends of extreme sea levels (Dixon & Tawn, 1994) provides a site by site analysis from the A-class tide gauge network of extremes around the coast of the UK. Further research has been conducted to produce a spatial analysis of extreme water levels every 20km around the coast of mainland Britain (Dixon & Tawn, 1997) but does not include Shetland.

The Admiralty have always provided information on tidal currents to assist in navigation. The Admiralty Charts usually have a selection of "Diamonds", i.e. locations indicated on the chart by a diamond symbol, with accompanying lists of current speeds at that point throughout the tide. In UK waters, this information is given for both Spring and Neap tides. The currents are usually "depth-averaged", i.e. an average value of the speed throughout the water column.

In addition the Admiralty also produce "Tidal stream atlases" with the offshore zone of Cell 11 covered in the *Orkney and Shetland Islands* (Hydrographer of the Navy, 1986). These show the currents over a wide area at various states of the tide. The flows are represented by arrows, annotated with the approximate speeds (again for Spring and Neap tides). However, this information is aimed at those navigating ships; it is rarely of much use in very shallow coastal waters or away from the main channels in estuaries.

Tidal current measurements are normally made over relatively short periods of time, (usually less than 1 year), often in connection with a particular study. There are two main sources of such data. Firstly the British Oceanographic Data Centre has a digital inventory of current meter data around the British Isles collected from a large number of both national and international organisations. The directory contains information up to 1991 and is available directly from BODC. The other source is from commercial survey companies carrying out site-specific studies. A number of tidal current measurements have been made in Yell Sound; elsewhere there is minimal information.

4.6 Wave data

Information on offshore wave conditions can be obtained from measured or recorded wave data or from synthetic wave data generated using numerical models. The only detailed record of instrumentally recorded wave data in Scotland is the MIAS catalogue (MIAS, 1982) which was compiled in 1982 and a catalogue compiled by Metocean (1994). An updated digital version is presently being developed. Wave recording is occasionally conducted by commercial organisations, normally in connection with marine construction projects, e.g. harbour developments. Waves have been instrumentally measured at three known positions, all well offshore of Shetland. These are detailed in Table 5.

Table 5 Cell 11 - Recorded wave information

Location	Lat/Long	Period covered	Mean Water Depth (m)	Contact
West of Shetland	60°31.00'N 002°52.00'W	26/07/84-21/12/88	184	UK Offshore Operators Association
West of Shetland	60°07.50'N 002°57.00'W	05/12/76-31/12/78	155	UK Offshore Operators Association
North East of Shetland	61°20.00'N 00°00.00'E	20/02/73-20/02/76	159	UK Offshore Operators Association

Information on wave conditions can also be obtained from the VOS (Voluntary Observations from Ships) archives. The majority of ships of passage make regular observations of wind and wave conditions as part of their routine duties. This information is collected worldwide and collated by the UK Meteorological Office. The records include date, time, location, wind speed and direction, significant wave height (H_s), zero-crossing period (T_m) and wave direction. Although not scientifically measured, VOS records have been found to be a useful source of data where there have been a large number of records spanning over many years, e.g. major shipping lanes. VOS data are available in the form of monthly, seasonal and annual frequency tables of wave height and period in 30° sectors for sea areas specified in 1° latitude and longitude squares. Details of the density of VOS data can be obtained from the Met Office.

When using VOS data it is important to ensure that the selected area is large enough to contain sufficient data in each sector for a reliable analysis of extreme conditions, but small enough to ensure that conditions are representative of the region of interest. In addition, for an analysis based on VOS observations to be valid, it is necessary to ensure that the exposure of the location of interest is the same as that of the VOS area used.

In many locations, offshore wave prediction using numerical modelling techniques is difficult. Around much of the UK coast it is necessary, as a minimum, to have a model which can predict the generation of waves over a substantial part of the sea or ocean, and then to "follow" those waves as they develop into swell. A number of such numerical models exist, all run by national meteorological offices, or other government departments. In the UK, the most appropriate model to use is the Meteorological Office European Wave Forecasting Model.

Two surface wave models are run at present on an operational (daily) basis at the UK Meteorological Office. These are the result of an evolving series of such models, in use since 1976. They were designed primarily for offshore application, for example in ship routing and operation of offshore structures. The model calculations are carried out on a polar stereographic grid, whose exact spacing varies from one latitude to another. The European Wave Model (grid spacing about 30km) is nested within the Global Model (grid spacing about 150km) from which it takes its boundary wave conditions. The 30km grid size means that shallow water effects are not well represented in the model, and grid points closest to the land are not used for prediction purposes. Before use at the shoreline, the model predictions therefore need to be transformed from 20-50km offshore to the coast (see below).

The models are run twice daily, driven by wind fields extracted from operational global weather forecasting models. They produce wave forecasts from 12 hours prior to the run-time ("T") up to 36 hours ahead, at 3 hourly intervals. As well as noting the time, date, latitude and longitude, each forecast gives the wind speed and direction, and the significant wave height, mean wave period and wave direction for the separate wind-sea and swell components and overall. The data from T-12 hours to T+0 hours are permanently stored in an archive, whilst the data from T+0 hours to T+36 hours are immediately disseminated for forecasting purposes. Sea state observations from fixed buoys, oil platforms, Ocean Weather Ships and, more recently, satellite wave measurements, are used for real-time "calibration" of the models, and also for periodic validation. The archived information provides a very useful "synthetic" offshore wave climate. Figure 6 shows the grid point locations offshore of Shetland.

Modern numerical methods are capable of accurate predictions of "wind-sea" for offshore areas, especially if there are good quality, sequential wind data available to provide the basic input conditions. The final stage in numerical wave prediction is to transform such offshore wave information into corresponding nearshore conditions. This may be carried out for just a few offshore conditions (e.g. waves expected to occur only in exceptional storms), or for a whole wave "climate". For further details of the range of numerical techniques available, the reader is referred to a recent report by Dodd and Brampton (1995). However, in outline all such models start from a digital representation of the water depths between the offshore point at which waves are predicted, and the stretch of coastline under consideration. A number of alternative techniques are available that calculate the way that wave energy propagates shoreward; they all include the processes of refraction and shoaling, and many can include other effects such as frictional dissipation, the shelter provided by offshore islands or headlands, the effects of tidal currents (particularly important at a number of locations within the channels which separate many of the islands) or the continuing growth of waves as they travel across the area being modelled. The accuracy of such transformation methods is generally good, provided an appropriate model has been chosen. The inshore wave climate has been derived at a number of locations along the coastline of this cell. These locations are detailed in Table 6 and shown in Figure 6.

Table 6 Cell 11 - Sources of numerically modelled wave conditions

Location	Offshore/Inshore Position	Period	Mean water depth (m)	Wave data	Contact
On a regular grid 0.25°lat. by 0.4°long.	Offshore: First point is normally less than 20km from the coast	1986 onwards	variable	Wind, swell and total sea climate and extremes	UK Met Office or HR Wallingford
Blacksness Harbour, Scalloway	Inshore: 60°07.90'N 1°17.07'W 60°08.03'N 1°16.47'W	-	-10m CD -8m CD	Offshore climate and extremes and inshore extremes: 50,200 & 1000 year events	HR Wallingford
Symbister (Whalsay)	Inshore: West of Symbister Harbour	-	-20m CD	1, 10 & 50 year extremes	HR Wallingford
Orka Voe	Inshore	-	-18m CD -6m CD	Wave climate	HR Wallingford

4.7 Natural and cultural heritage

Information on statutory designations and protected sites of natural heritage importance, and on certain non-statutory sites, is provided by Scottish Natural Heritage. A description of the various designations is given in Section 3.6.

Within Cell 11 the number of designated natural heritage sites is given in Table 7. The locations of Sites of Special Scientific Interest is provided in Figure 7 with further information detailed in Appendix 1. Other natural heritage designations are shown in Figure 8.

Table 7 Cell 11 - Natural heritage designations

Designation	Number	Designation	Number
SSSI	57	NSA	1 (7 parts)
NNR	3	NHA	-
MNR	-	AGLV	-
LNR	-	ESA	-
SAC	7	MCA	4
SPA	6	RSPB	3
RAMSAR	-	LWT	-

Note: Data correct to September 1996. Supplied by Scottish Natural Heritage.
The distribution of designated SACs and SPAs has changed significantly since these data were compiled.
Details of recent additions to this network can be obtained from Scottish Natural Heritage.

The Royal Commission on the Ancient and Historical Monuments in Scotland (RCAHMS) maintain a GIS database (National Monuments Records of Scotland, NMRS) with the locations of scheduled archaeological and historical sites. Only the location of sites within 50m of the coastline was requested from the RCAHMS in this study. However, the RCAHMS advised that to locate all coastal sites would require a resolution of 500m from the coastline. Figure 9 shows the relative density of scheduled archaeological and historical sites extracted from the NMRS database within 500m wide by 10km long strips along the coastline of Cell 11. Because of the low resolution these will include a large number of sites which are not truly coastal. Appendix 2 shows the actual locations of scheduled sites within 500m of the coastline obtained from the RCAHMS GIS database.

Table 8 Cell 11 - Information sources for sites of cultural heritage

Advice or information on:	Contact
Scheduled monuments	Historic Scotland
Designated wrecks	Historic Scotland
The protection & management of sites and monuments	Historic Scotland or Regional Archaeologist
Sites or monuments already known	Historic Scotland/Regional Archaeologist/RCAHMS
Archaeological remains discovered during development	Historic Scotland/Regional Archaeologist
The discovery of a site	Regional Archaeologist/RCAHMS
An isolated artefact find	Regional Archaeologist/National Museums of Scotland/Local Museum
Damage to a scheduled monument	Historic Scotland
Damage to an unscheduled monument	Regional Archaeologist

Adapted from *Archaeological and Historical Advice in Scotland* available from Historic Scotland.

Only where more detailed surveying has been conducted can an assessment of the number of coastal sites at risk from marine erosion be determined. Some survey work has been conducted by the Shetland Amenity Trust which has identified at least 92 sites of cultural heritage which are presently experiencing marine erosion. There are also a large number of sites, such as Listed Buildings, which do not appear in the NMRS database

5 *Cell 11: Shetland*

5.1 General

Cell 11 is defined as the Shetland Island coastline. The concept of coastal cells, as defined in Section 2.1, is not really applicable to the Shetland Islands as there are no areas of continuous, or semi-continuous, "soft" coastline. Beach areas tend to be pocket beach types which, at present sea levels, tend to have little longshore sediment transport either within the beach units or between units. This section concentrates upon the beach or "soft" coast areas of this cell largely ignoring the rocky coast.

The cell has been split arbitrarily into two sub-cells based on the exposure to the wave climate. Sub-cell 11a encompasses the eastern facing coastline of the Shetland Islands with Sub-cell 11b, the western coast. Sections 5.2 to 5.3 describe the coastal regime occurring within Cell 11.

Within each sub-cell relatively self contained beach units can also be identified. For example there is unlikely to be significant interchange of beach material between most of the individual beach areas Cell 11. The locations of these "semi-independent beach units" are shown on the relevant littoral process maps

5.2 Cell 11: Physical characteristics

5.2.1 General

The characteristics of Cell 11 and processes occurring within it are described under the headings of Geology and geomorphology, Hydraulic processes, Littoral processes and Coastal defences and monitoring.

The geology and geomorphology of the coastline of Scotland is an extremely complex topic with few detailed texts on the subject. Only a brief description is provided within this report in the context of the influence of the solid geology on present day coastal processes and the geomorphological features evident around the coastline. The drift deposits occurring within each sub-cell are shown in Figure 10.

Details of the dominant hydraulic processes, i.e. the tides, currents and waves are described. Tidal elevations within each sub-cell are described and, where known, details of any surge information. The direction of the main tidal currents and magnitude of tidal velocities also detailed. Any areas where significant tidal flooding occurs are noted. The offshore wave climate (both total sea and swell) has been predicted from the Met Office Wave Model along with a range of extreme offshore wave conditions. The dominant nearshore processes which affect the transformation of offshore to inshore wave conditions are also described.

The next section within each sub-cell describes the main littoral processes. The dominant beach sediment sources and sinks are described. Where possible the main nett longshore transport directions are detailed with an indication of the dominant forces causing this drift. Known areas of long term nett erosion and accretion are also described. Where more detailed engineering studies have been conducted, these have been referred to for any indication of erosion or accretion rates. Locations where man-made development in the coastal zone has altered the littoral regime are also described. Details of the foreshore and hinterland characteristics are shown in the relevant figures for each sub-cell along with the dominant littoral processes. Locations where maintenance dredging is conducted are mentioned and, where possible, any known dredging rates and sources of siltation.

The final section details the location, type and influences of coastal protection. Where possible the length of coastline protected has been given along with a brief indication of the present state of the defences and any significant impacts on the coast due to these works. Locations where beach monitoring or coastal surveys have been conducted are mentioned and, where possible, details of the length of such records and monitoring authorities given. Details of existing coastal defences and locations where regular monitoring is conducted are shown in the relevant figures for each sub-cell.

5.3 Sub - cell 11a: Shetland East - Sumburgh Head to Herma Ness

5.3.1 Geology

The solid geology of the Shetland Islands is largely composed of ancient metamorphic and igneous rocks, particularly to the east of the Walls Boundary Fault which dissects the Mainland between Sullom Voe and The Deeps. The eastern coastline is heavily faulted and this has produced a complex structure. The trends are generally north to south with bands of basic and acid intrusive igneous rocks, metamorphic limestones and hornblende schists present.

Sedimentary and volcanic rocks of Devonian age unconformably overlie the basement rock in places, particularly on the west coast. Such deposits are less evident on the east coast of Shetland, although over much of Bressay, and the coastal edge of the mainland between Bressay and Sumburgh Head, Old Red Sandstone (ORS) outcrops occur. Around Sumburgh Head and the immediate coast to the north, this tends to be Middle ORS, with Upper ORS deposits occurring at Bressay and around Lerwick.

Erosion of this bedrock has supplied little beach material in Shetland except in a number of small sandy bays where a proportion of the beach material has derived from erosion of Old Red Sandstone outcrops. Unlike the west coast of mainland Scotland, the offshore bathymetry tends to be steep immediately offshore with rock reefs and outcrops having less of an influence on nearshore wave conditions. However, most of the beach systems are constrained between rock outcrops or headlands which have a significant effect on the planshape development of the beaches.

Glaciation had a considerable effect on the Shetland Islands with ice-scouring smoothing out the original relief to produce the present day rounded landscape. Glacial deposits are limited to a thin layer of till which variably caps the underlying bedrock. The character of this till varies according to the bedrock underneath but has generally a stony matrix. Marine erosion of this till has provided material for the formation of beaches in a number of areas. Unlike the majority of mainland Scotland there is no evidence of previous raised sea levels in Shetland. There are no raised beaches or well defined shore platforms above present sea levels. Instead, since the end of the last Ice Age, Shetland appears to have been experiencing submergence of the land. It is thought that Shetland had a much thinner ice cover than mainland Scotland and so underwent less isostatic depression. Consequently, since retreat of the ice, it has undergone less isostatic recovery than mainland Scotland with any such recovery being outpaced by global rises in sea level. Hence there is little postglacial sediment found in the coastal hinterland, apart from small areas of blown sand.

5.3.2 Hydraulic processes

The mean spring and neap tidal ranges for this sub-cell are shown in Figure 11 and detailed in the table below. The mean spring tidal range varies from around 1.4m at Sumburgh, in the south, to 2.0m in Burra Firth at the northern end of the sub-cell. The corresponding neap range varies from about 0.7m in the south to 1.0m in Burra Firth.

Table 9 Sub-cell 11a - Predicted tidal levels and ranges

Location	MHWS (m CD)	MLWS (m CD)	Spring Range (m)	MHWN (m CD)	MLWN (m CD)	Neap Range (m)	CD to OD (local) (m)
LERWICK	2.2	0.6	1.6	1.7	1.0	0.7	-1.22
Sumburgh	1.8	0.4	1.4	1.4	0.7	0.7	-
Dury Voe	2.1	0.3	1.8	1.6	0.9	0.7	-1.30
Out Skerries	2.2	0.4	1.8	1.7	0.9	0.8	-
Toft Pier	2.3	0.4	1.9	1.8	0.8	1.0	-
Burra Voe	2.3	0.4	1.9	1.8	0.9	0.9	-1.24
Mid Yell	2.4	0.6	1.8	1.9	1.1	0.8	-1.38
Balta Sound	2.3	0.4	1.9	1.8	0.9	0.9	-1.28
Burra Firth	2.5	0.5	2.0	1.9	0.9	1.0	-1.37

In Table 9 the tidal elevations are quoted relative to Chart Datum for each location. The conversion to Ordnance Datum (Local) is shown in the final column. Note that Ordnance Datum (Local) is not the same as Ordnance Datum Newlyn (the standard land based datum used on the UK mainland).

There is little information on extreme water levels within this sub-cell. The 1:50 year return period surge is given to be between 0.75m and 1.0m around Shetland (BODC, 1991). Estimates of extreme water levels have been made at A-class tidal gauge locations by Graff (1981), shown in Table 10, and by Dixon & Tawn (1994) who have extended their work to provide a spatial estimate every 20km around the mainland coast (Dixon & Tawn, 1997). The extreme water level predictions provided at Lerwick by Dixon & Tawn depend on the year of interest and also allow for mean sea level rise.

Table 10 Extreme sea levels in Sub-cell 11a

Graff (1981):

Location	Return period levels (m ACD (1990)) calculated for 1990					
	5	10	20	50	100	250
Lerwick	1.5	1.56	1.58	1.63	1.67	1.7

The main flood stream east of the Shetland Islands flows to the south with the tidal stream tending to rotate in a clockwise direction. Around low water the flow direction is to the north. Off the coast the rates are low generally less than 0.25ms^{-1} on a Spring Tide. However, off the salient points (e.g. headlands) and in the channels between the islands the current rates can be much greater leading to many eddies forming, for example in the lee of small islands. These streams tend to be strongest on both flood and ebb in Bluemull and Colgrave Sounds, Yell Sound and between Whalsay and the Mainland. It is unlikely that tidal currents significantly influence beach processes on the east coast of Shetland.

The Met. Office European Wave Model has been used to predict the offshore wave climate to the east of the Shetland Islands and is shown in Figures 12 and 13 for the total sea and swell sea respectively. The wave climate is dominated by waves from two sectors. Approximately 60% of wave conditions are experienced from between 120°N and 240°N with 30% of wave conditions experienced from 340°N to 40°N. Significant wave heights of over

8m are experienced from either of these directional sectors. Due to the shelter provided by the Shetland Islands to the west and the relative lack of strong winds from due east, there is little wave activity outwith these directional sectors.

Table 11 Total sea and swell extreme significant wave heights east of Shetland

Return Period (Years)	Total sea extreme significant wave height (m)	Swell sea extreme significant wave height (m)
1	9.28	4.18
10	10.88	5.09
100	12.36	5.94

Dominant swell wave conditions are experienced from the north with over 40% of swell conditions occurring from between 340°N and 20°N. Severe significant swell wave conditions (in this case over 4m) are restricted to only a few, narrow directional sectors, to the south east and to the north. Extreme swell conditions are also detailed in the above table.

There is very little information on inshore wave conditions along the eastern seaboard of the Shetland Islands. The immediate seabed tends to be relatively steep (e.g. the 50m CD contour runs close to the shoreline all along the eastern seaboard) resulting in there being little wave energy dissipation between the severe offshore wave conditions and waves close to the shore. The degree of severity of wave conditions upon the shoreline depends very much on the orientation of the beach. On the east coast there are very few beaches which are orientated so as to be directly exposed to severe offshore wave conditions. The only location known where inshore wave conditions have been predicted on the eastern coastline of the Shetland Islands is at Symbister Harbour on Whalsay (HR Wallingford, 1986). The wave conditions at three inshore locations, just to the west of Symbister Harbour, emphasised the highly variable nature of the inshore wave conditions even over relatively short distances largely due to the changes in exposure. On this coastline it is impossible to make generalised comments upon the wave conditions experienced along the shoreline. Individual predictions are required for each individual site.

5.3.3 Littoral processes

Apart from the *Beaches of Shetland* report (Mather & Smith, 1974) there has been little study conducted of beaches in the Shetland Islands with virtually no published information on littoral processes or rates of erosion. The quantity of beach material available for the formation of the beach areas on the eastern coast of Shetland is extremely restricted. On mainland Scotland and in the Western Isles offshore glacial deposits have supplied a large percentage of the beach material occurring around these coastlines. Offshore of the Shetland Islands the seabed slope is steep and dominantly rocky with sparse sand deposits. Hence, offshore glacial material is not a major source of beach sediments. Much of the shingle and cobble beach material will have derived from marine erosion of glacial till deposits which overlie the solid geology over much of the islands. This is likely to have been the main source of beach material for most of the beach units along the south east coastline of the mainland, Figure 14. Cliff erosion has also provided an input of material at a number of locations, notably at Wick of Tresta on Fetlar, and on the beaches of Skaw on Unst. The final significant source of beach material is from fragmented shell material, with a high shell content noted particularly on the beaches to the south of Lerwick and those in the vicinity of Balta Island off Unst.

The supply of fresh beach material at all sites on the east coast of Shetland is extremely limited. Erosion of till deposits and cliffs is still occurring but at present this is supplying a very low feed of beach material. Similarly, shell deposits do not provide a large volumetric rate of fresh material.

Littoral processes on all beaches on the east coast of Shetland are wave dominated. The constructive influence of the incident wave action can be seen in the range of built features, such as the many tombolos and spit features, one of the most impressive on the east coast being at The Houb where a triple tombolo and spit feature links Fora Ness to The Mainland.

Most of the sand and shingle beaches have developed into equilibrium bay shapes which are dependent upon the incident wave directions (particularly swell waves), i.e. there is little evidence of longshore transport processes, Figure 15. However, the severity of wave conditions experienced upon this coastline still tends to have a predominantly destructive influence upon the beach areas with erosion of the coastal edge a common feature on the majority of the beach areas. This is generally limited to episodic events, i.e. storm conditions, but such events can be relatively frequent off the Shetland coast. Due to the lack of fresh beach material and the influence of the destructive wave conditions often experienced along this coast there are few area of accretion.

Little information is available on present day erosion rates, but it is unlikely that there will have been any significant changes in the patterns of erosion from those noted by Mather and Smith in the *Beaches of Shetland* (Mather & Smith, 1974).

Little dredging has been conducted in Shetland. The only location in Sub-cell 11a identified in the UK Dredged Material Licence Database (MAFF, 1995b) is maintenance dredging at Scalloway conducted by Shetland Islands Council which was dumped in Punds Voe. There is no information on sediment movement of the dredged spoil but it is unlikely to have any significant detrimental or beneficial influence on the beaches of this sub-cell.

Summary of Erosion and Accretion

Long-term erosion is occurring on all beach areas within this sub-cell. However, there is little present day information on rates of retreat or which sites are the worst affected.

5.3.4 Coastal defences

There are few coastal defences within this sub-cell other than harbour works at Lerwick and Symbister, Figure 16.

5.4 Sub - cell 11b: Shetland West - Herma Ness to Sumburgh Head

5.4.1 Geology

The solid geology of the western coast of the Shetland Islands is split into two by the Walls Boundary Fault which dissects the coast between The Deeps and Sullom Voe. To the east of the fault, the western coastline on the southern Mainland and that of Yell and Unst are similar in character to the eastern coastline of the Islands with the solid geology largely composed of heavily faulted metamorphic and intrusive igneous rocks.

Metamorphic schists and gneisses (mainly metasediments) occur immediately to the west of the Walls Boundary Fault along the coastline of Sullom Voe and Yell Sound. On the northern tip of the mainland acid and hornblendic gneisses of Precambrian age occur. Over much of the northern mainland between the metamorphic rock and the Melby Fault intrusive igneous complexes, mainly of granite and pegmatites (graphic granite), occur. The headlands of Esha Ness and The Faither, and the island of Papa Stour, are composed of Old Red Sandstone but are overlain by basic igneous lavas and tuffs of around the same age.

Overlying the basement rocks over the Walls Peninsula, Old Red Sandstone deposits occur. These form an immensely thick outcrop of Lower to Middle ORS which can be seen along the steep sea cliffs on this coast.

As detailed in Section 5.3.1, the effects of the Ice Age have had a largely erosional influence on the Shetland Islands. Glacial deposits are generally limited to thin layers of stony till which cap the solid geology. Similarly, there is no evidence of raised beaches, the beach units which do occur generally being poorly nourished with sediment. Postglacial deposits, mainly of blown sand, do occur most evidently at Quendale and less so at a number of other locations.

5.4.2 Hydraulic processes

The mean spring and neap tidal ranges for this sub-cell are shown in Figure 11 and detailed in the table below. There are no A-class tidal gauges within this sub-cell, the nearest being Lerwick. The mean spring tidal range is around 1.4m at Sumburgh, in the south, and 2.1m in Bluemull Sound at the northern end of the sub-cell. However, the spring tidal range is lowest around Scalloway and Bay of Quendale (being around 1.1m). The corresponding neap range varies from about 0.7m in the south to about 0.9m in Bluemull Sound. Table 12 details the predicted tidal levels for this sub-cell. As Ordnance Datum is relative to local and not relative to Ordnance Datum Newlyn the values are quoted relative to Chart Datum with the conversion factor to Ordnance Datum (local) provided in the final column (where known).

Table 12 Sub-cell 11b - Predicted tidal levels and ranges

Location	MHWS (m CD)	MLWS (m CD)	Spring Range (m)	MHWN (m CD)	MLWN (m CD)	Neap Range (m)	CD to OD (local) (m)
Sumburgh	1.8	0.4	1.4	1.4	0.7	0.7	-
Bay of Quendale	1.7	0.6	1.1	1.4	0.9	0.5	-
Scalloway	1.6	0.5	1.1	1.3	0.6	0.7	-
Hillswick	2.0	0.4	1.6	1.6	0.8	0.8	-0.8
Sullom Voe	2.2	0.4	1.8	1.7	0.8	0.9	-1.4
Bluemull Sound	2.6	0.5	2.1	1.9	1.0	0.9	-1.4

There is little information on extreme water levels within this sub-cell. The 1:50 year return period surge is given to be between 0.75m and 1.0m around Shetland (BODC, 1991). Estimates of extreme water levels have been made based on tidal data from the A-class tidal gauge network Graff (1981), (Dixon & Tawn, 1994). The predictions reported by Graff for Lerwick, are shown in Table 10, Section 5.3.2.

The main flood tide flows to the south east along the south west coast of the mainland and to the north east along the north west coast. Current speeds offshore are generally relatively low except around the northern coastline of Unst and Sumburgh Head in the south. Strong tidal currents do not tend to act close to the shoreline and are unlikely to have any significant influence on littoral processes on the western coastline of the Shetland Islands.

The Met Office European Wave Model has been used to predict the offshore wave climate to the west of the Shetland Islands and is shown in Figures 16 and 17 for the total sea and swell sea respectively. The wave climate is dominated by waves from a relatively narrow sector to the south west with 45% of wave conditions experienced from between 220°N and 280°N. However, severe wave conditions (significant wave heights greater than 8m) can be experienced from any direction in the westerly sector. Using the Met Office data, the extreme offshore wave heights experienced to the west of the Shetland Islands are detailed in the Table below:

Table 13 Total sea and swell extreme significant wave heights west of Shetland

Return Period (Years)	Total sea extreme significant wave height (m)	Swell sea extreme significant wave height (m)
1	10.88	5.33
10	12.89	6.57
100	14.75	7.74

Swell wave conditions are dominated by swell generated in the Northern Atlantic with 65% of swell experienced from 240°N and 300°N. Extreme swell conditions can be significant and are also listed in the table above.

There is very little information on inshore wave conditions along the western seaboard of the Shetland Islands. As with the east coast, the immediate seabed tends to be relatively steep (e.g. the 50m CD contour runs close to the shoreline all along the western seaboard) resulting in there being little wave energy dissipation between the severe offshore wave conditions and waves close to the shore. The degree of severity of wave conditions at the shoreline depends very much on the orientation of the beach. On the west coast most of the beach units are in sheltered locations and are not orientated to experience the most severe wave conditions. The only locations known where inshore wave conditions have been predicted are at Blacksness Harbour at Scalloway (HR Wallingford,1989, 1993b) and within Orka Voe (HR Wallingford, 1976). On coastlines such as the west coast of Shetland it is impossible to make generalised comments about the wave conditions experienced at the shoreline. Individual predictions are required for each individual site.

5.4.3 Littoral processes

There has been little study of the beach areas on the west coast of Shetland, other than the Beaches of Shetland report (Mather & Smith, 1974) and studies by Flinn (undated, 1997) at St Ninian's tombolo.

As on the east coast, very little beach sediment has been derived from offshore glacial deposits due to the lack of such deposits and the steep offshore bathymetry to the west of the Shetland Islands which is not conducive to the onshore movement of large volumes of beach material. Beach material is derived from three main sources, fragmented shell material, marine erosion of glacial tills and cliff erosion, Figure 14. Till and shell material form the majority of the beach sediment on most of the beach units on the western coastline of Shetland. At a number of beaches along the south western coastline of the mainland, shell is the dominant component. Despite the exposed nature of the coastline, erosion of cliffs only provides an input of beach material at a few sites. For example erosion of Old Red Sandstone cliffs has provided an input to beaches in the Papa Stour area. Cliff erosion, through both marine erosion and weathering, is also the primary source of the cobbles and boulders for the beach at Lang Ayre on the north west coast of the mainland, Figure 15.

The supply of fresh sediment to the beaches on the west coast of Shetland will always have been low. Erosion of the cliff areas and till deposits will be ongoing, and there will still be some input from shell sources. However, the rate of this fresh supply will be insufficient to maintain a stable sediment budget.

Due to the west coastline of Shetland being dominated by rock, beaches tend to be independent with no large scale longshore littoral processes occurring. The beaches occurring along this coastline are dominantly pocket beach types, constrained by "hard" coastline at either end. Such beaches tend to be relatively "sediment tight", i.e. despite there being little fresh input of beach material there is also little loss of material. However, on virtually all beaches losses, either offshore or by sand blown into the hinterland, are exceeding fresh supply and evidence of episodic storm erosion of the coastal edge is apparent on most beaches. Only at locations where there are significant volumes of beach material "stored" in the hinterland dunes, such as Bay of Quendale, is a healthy beach maintained.

There has been a problem, in recent years, of beach erosion in Sumburgh Bay, with the modest dune belt in the north western corner eroding. Sand has blown inland, on occasions partly blocking the coastal road that runs between the dunes and the airport. No defences have been installed, but periodic surveying is being carried out to monitor the situation. It seem likely that this erosion is a short-term response to a period of severe wave conditions (including the "Braer" storm on 5 January 1993) rather than a change in the morphological regime of the bay.

The tombolo which links St Ninian's Island to the Mainland is an extremely stable feature due to the low tidal range and uni-directional nature of the heavily diffracted and refracted wave conditions on either side of the tombolo. The feature is in dynamic equilibrium with the incident hydraulic conditions and although seasonal changes and periodic storm damage do occur there appears to have been little overall change in the feature over the last 300 years or so (Flinn, 1997). However, such a feature is extremely sensitive to any long term changes, particularly in water level, which could change the wave conditions experienced at the shoreline. This is discussed in Chapter 6.

Little dredging has been conducted in Shetland. The only location is sub-cell 11b, identified in the UK Dredged Materials Licence Database (MAFF, 1995b), is capital dredging in Bressay Sound by Lerwick Harbour Authority. The dumped dredged spoil was dumped within the Sound (the exact location is not known). This material is unlikely to have any significant detrimental or beneficial influence on the beaches of this sub-cell.

Summary of Erosion and Accretion

Long-term erosion is occurring on all beach areas within this sub-cell. However, there is little present day information on rates of retreat or which sites are worst affected.

As Shetland has not experienced periods of higher sea levels the influences of climatic change are going to be particularly noticeable in the erosion of beach areas. This is discussed more fully in Chapter 6.

5.4.4 Coastal defences

There are few coastal defences within this sub-cell other than harbour defence works, mainly at Scalloway, Figure 16. Any other defences tend to be extremely localised with minimal impact on beach areas.

5.5 Summary of effects of coastal processes on natural and cultural heritage sites

5.5.1 Introduction

The natural and cultural heritage of the coastline of Scotland is rich and diverse. Much of the character and many of the features of natural heritage interest are due to the effects of the last Ice Age and subsequent postglacial climatic variations. It is since the last Ice Age that evidence of the first inhabitants of Scotland can be traced. Effects of coastal processes have been instrumental in developing both the natural and cultural heritage around the coast. For instance many important coastal geomorphological features evident are due to processes acting at previously much higher sea levels. Archaeological sites also demonstrate changes in these processes over the last 10,000 years or so. For example Skara Brae in Orkney, now requiring engineering protection from the sea, was once some considerable distance from the shoreline. Remains in Gleann Sheillach south of Oban indicate that 6000 years ago this site was at the head of a sea loch even though now it is 1.5km from the shoreline (Ashmore, 1994).

The present threat of erosion and the likelihood of future climatic changes considerably increases the risks of many of these sites being affected by erosion and/or flooding. However, as discussed in the next chapter, our present knowledge of either the patterns of future climatic change or how the coastline will respond to these changes is extremely limited. It is impossible at present to predict with any confidence what changes will occur in the coastline for example in the next 100 years or indeed in the next 10 years. However, the next sections attempt to present a broad based summary of the influences of present day and possible future coastal processes upon natural and culturally designated areas. This report is concerned with the macro-scale processes occurring around the coastline. To generalise about the effects of coastal processes, particularly on individual cultural heritage sites, is extremely difficult, and many such sites require much more detailed, individual assessments to establish and prioritise the particular potential risks.

5.5.2 Natural heritage sites

Figure 7 details the location of coastal SSSIs within Cell 11, with a summary of their main characteristics provided in Appendix 1. There are 57 coastal SSSIs in Shetland, a large number of them designated, or partly designated, on account of the solid geology.

Sites designated on account of their solid geology will not undergo significant changes in the short term due to present day coastal processes. However, the situation on Shetland is different from that presently experienced on much of mainland Scotland. Around the coastline of mainland Scotland, uplift of the land due to isostatic recovery, has resulted in many of the cliffs and rock outcrops being above present day wave influence, i.e. they are relict features. In Shetland, global sea level rise has outpaced isostatic recovery and the coastline is instead characterised by long term submergence. Hence wave action is still very much an active process on most of the geological features and land forms evident around the coastline of Shetland. Although present day coastal processes, due to the severity of the wave conditions experienced around the coastline of Shetland, are resulting in long term erosion of most of the cliff areas, it is these wave processes which have formed many of the features upon which the designations have either been based, such as stacks or geos, or which have exposed features of importance. It should be stressed that this ongoing erosion is occurring at an extremely low rate.

The beach areas in Shetland are dominated by wave action which has a constructive and a destructive influence. There are a number of designated land forms which have been formed by the constructive process of wave action. The most well known is St Ninian's tombolo, but there are others, such as The Ayers of Swinister, and a whole range of similar tombolo and spit features which are not designated. At present these appear to be dynamically stable features. The constructive influence of wave activity is no longer continuing to develop these features, but it does "repair" storm damage. This can be seen at St Ninian's tombolo which is showing little long-term change. During severe weather conditions the elevation of the tombolo can be drawn down with sand tending to be moved to below low water. However, in the months after such events, this sand is restored to the beach under swell wave conditions. At the Ayres of Swinster, the tombolo and spit features are composed of shingle and as such are much less dynamic than the sand tombolo of St Ninian's. Present day coastal processes are unlikely to alter this feature significantly.

5.5.3 Cultural heritage sites

The location of archaeological sites from the NMRS database is shown in Figure 9. There has been no specific coastal survey for the Shetland Islands to establish the threat of coastal erosion on sites of historic and archaeological importance (Ashmore, 1994). However, considerable work has been conducted by the Shetland Amenity Trust. This has identified at least 92 sites which are considered to be suffering from marine erosion. Given the present state of the beaches in Shetland the threat or risk to these sites is not going to improve and, if anything, is likely to increase. It would appear advisable to conduct a survey, as a matter of urgency, of the most important sites.

To provide general guidance on the sites most at risk is an impossible task for Shetland. Damage to cultural heritage sites in the immediate hinterland due to marine erosion will dominantly occur due to storm wave action, i.e. erosion will be mainly due to episodic events. The magnitude of erosion at each individual site will be dependent upon the orientation of the coastline, the degree of shelter provided by offshore islands or headlands, and the direction of the storm. As the coastline is highly irregular and indented, storm damage will vary from site to site, even over extremely short distances.

6 *Climate change and its effect on coastal management*

6.1 Introduction

The importance of climate change in the context of coastal management has generally been equated to the problems caused by an increase in mean sea level. This remains an important issue, particularly for low-lying areas where economically important assets are situated close to, or below, extreme tide level. However, recent winters in the UK have indicated a number of other potential impacts affecting the management of the coastline and its defences which may be more important, at least in the short-term. Such factors include an increased frequency of storms. Increased erosion of the coast may therefore be a greater concern in much of Scotland than flooding due to sea level rise. Much of Section 6.2 is taken from Brampton (1996).

6.2 Evidence of climatic change

6.2.1 General

The Intergovernmental Panel on Climate Change (IPCC) concluded that 'The balance of evidence from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate' (Houghton *et al.*, 1996). The conclusion of the IPCC rests on: (i) the physical effect of greenhouse gases on the atmosphere; (ii) observed climatic trends; and (iii) projections from global climate models.

The greenhouse effect results from certain gases in the atmosphere retaining heat that would otherwise be radiated into space. These greenhouse gases are relatively transparent to sunlight but absorb thermal infrared radiation emitted by the Earth's surface. The natural greenhouse effect already keeps the Earth over 30°C warmer than it otherwise would be; increasing concentrations of greenhouse gases warm the Earth still further.

The main greenhouse gases are carbon dioxide, methane, nitrous oxide and some industrial chemicals such as chlorofluorocarbons (CFCs) but also include water vapour. Significant modification of the atmosphere by human activities has occurred since the industrial Revolution. However, the magnitude of greenhouse gas emissions has increased enormously in recent decades. Increased carbon dioxide is the most important driver of global change contributing about 64% of the radiative forcing that produces global warming (Houghton *et al.*, 1996).

Global average surface air temperatures can be computed back to 1856. The record shows warming of about 0.5°C over the 140-year period to 1997, with the warmest year occurring in 1997 and the warmest six years all recorded since 1983 (Parker & Folland, 1995). The decade 1987-1996 has been 0.25°C warmer than the 1961-90 average.

6.2.2 Tidal and sea level change

Geomorphological evidence shows a long-term pattern of sea level rise relative to the land around much of the UK coast, stretching back over 10,000 years to the end of the last Ice Age. Generally rates of sea level rise during this period have been higher than they are today although there have been several periods of "stands" in level, or even periods of falling levels. However, since the end of the last Ice Age, the isostatic uplift of the land mass due to postglacial recovery (in mainland Scotland at least) has been occurring at a greater rate. The net result has been a fall in sea levels relative to the land level in most of Scotland, except for the Northern and Western Isles where gradual submergence has continued. Evidence for this is largely from geological features such as raised beaches which are a common occurrence around much of the Scottish coastline. The rate of isostatic uplift since the last Ice Age has been one of an exponential decrease and at present over much of Scotland the rate of increase in sea levels (eustatic increases) is now occurring at a slightly greater rate, i.e. sea levels are now increasing relative to land levels albeit at a very low rate (and certainly a much lower rate than say experienced on the south east coast of England). Whilst the Intergovernmental Panel on Climate Change (IPCC) (Houghton *et al.*, 1996) estimates a global mean sea level of 12-95cm higher than 1990 by the year 2100, the rise around the Scottish coast is expected to lie at the lower end of these values. Estimates by Hill *et al.*, (1999) indicate that the net mean rise in sea level around the Scottish coast by 2050 will be up to 30cm with nearly a third of the coastline only experiencing a rise up to 10cm, although the Shetland Isles may experience a net rise in sea level greater than 30 cm. These regional variations reflect differences in the rate of crustal uplift across the country which moderate or exacerbate, locally, the global rise in sea level. The term "net rise" means that land uplift rates are taken into account.

It is important to note that an increase in extreme tidal levels may not, in the short-term, be the same as an increase in mean sea levels. There is not only a long-term variation in the height and frequency of surges (as in wave heights, see Section 3.3), but also a change in the range of the astronomical tides. This latter aspect has been observed, for example in Newlyn, but not apparently explained. An increase in extreme tidal levels might be expected to increase the chances of wave overtopping of beaches and coastal defences or to increase dune erosion.

However, the evidence for this is far from conclusive. Recent research (Woodworth et al, 1991) carried out by the Proudman Oceanographic Laboratory analysed the long-term tide record from Newlyn in Cornwall. This has indicated the influence of the 18.6 year periodicity (caused by the precession of the plane of the Moon's orbit around the Earth, relative to the elliptical plane). During certain stages of this 19-year cycle, the mean tidal ranges increased by about 20mm/year, and it can be expected that the spring tidal ranges will increase by an even greater amount. This effect lasts for several consecutive years. During such periods, the effects on the upper parts of the beach would presumably be much the same as if mean sea level was rising by about half that amount, i.e. about 10mm/annum. Therefore it can be assumed that there would be periods of rapid beach erosion and landward recession during these times (presumably followed 9 years later by periods of beach accretion as high water levels decline). At present we are at the end of one of these rapid rise periods.

6.2.3 Wave climate change

Wave action around most of the coastline of the UK is the principal mechanism affecting evolution of the nearshore zone, i.e. the region where water depths are less than 5m at low tide. Hence changes in wave heights, either in terms of general trends or in severe storms, are of considerable importance. There is now no doubt that such increases in wave height do occur and may continue to do so for some considerable time. Bacon and Carter (1991) have conducted the most comprehensive review available of wave climate changes in the North Atlantic and North Sea. Their data suggests that mean wave height increased from about 1960 to a peak around 1980, with a subsequent decline. Recent winters, (particularly 1988-1989 and 1993) have produced severe storms in the northern North Sea which may affect these trends. This agrees with more recent work (Leggett et al, 1996) which analysed wave climate data in the northern North Sea between 1973 and 1995 and concluded that:

- in the northern North Sea mean significant wave heights (H_s) have increased by approximately 0.2-0.3m (5-10%) since 1973. Wave conditions have been higher since 1988/89, with a secondary peak in 1982/83.

- Peak H_s values since 1988 have generally been significantly higher than those from the period 1973-1987. Recent years have seen storms with peak H_s of 12.5-14m, whereas peak values recorded before 1987 were around 11-12m.

- Since the 1980s wave conditions appear to have become a little calmer in autumn and more severe in late winter.

There is also some qualitative information to suggest that the increase in severity of the wave climate in the North East Atlantic has occurred in parallel with an increase in the frequency of very deep low pressure systems in the North East Atlantic (Lynagh, 1996). This report suggests that the latest peak in the frequency of occurrence of these low pressure systems may be over and that the next few years will see a decrease in such systems. However, there is insufficient evidence to confidently predict whether such a decrease will occur or indeed if these variations are linked to variations in storminess.

Wave direction can be almost as important as wave height in coastal management. Any changes in long term average wind directions can cause large morphological changes. There is not a sufficient length of time series of reliable directional wave data to assess any trends in direction. Analysis of wind climate data has revealed that there has been very little change in the wind climate and no proof that recent increases in storminess are statistically significant. Unpublished work by Jenkinson and Collison (1977) found no significant change in wind speeds over the Atlantic or North Sea occurred between 1881 and 1976. Historical evidence analysed by Lamb and Weiss, (1979) detected a climatic cycle of about 200 years. Over the North Sea the change consisted mainly of changes in the relative proportions of northerly and westerly winds. At present, it was reported, we are experiencing an increase in the proportion of northerlies which may lead to an increase in mean wave heights affecting the east coast. It was forecast that this trend would continue for a further 70 to 100 years. However, there has been some concern that depressions from the Atlantic have been tracking further to the south than previously. This has increased the dominance of south easterly winds potentially affecting the rate (even the direction) of the nett alongshore drift at various locations. There is no available information to confirm whether this is a long term trend.

6.3 Effects on coastal management

6.3.1 Impact on beaches

General

One method for predicting shoreline erosion caused by sea level rise is known as the Bruun Rule (Bruun, 1983). This suggests that as sea levels rise, the beach will adjust to maintain a constant depth profile, i.e. the upper beach erodes, while the nearshore bed accretes. There is some evidence to suggest that this also happens in real life, but it should be realised that the method assumes a two-dimensional response when the development of a beach will almost always be three dimensional. The amount of sediment available is also a critical factor in the response of a beach to sea level rise, with those with a limited supply being more likely to retreat.

In the UK, the effect of sea level rise on beaches is probably not as great as those associated with changes in the wave climate, in the short term at least. An increase in the occurrence of very large waves will, for example, alter beach profiles or cause dune erosion which may take many months, or even years, to repair naturally. Conversely an increase in the occurrence of more modest waves, may be accompanied by a decrease in the largest wave heights. This would lead to a general steepening of the beach profile and a reduction in erosion. A change due to sea level rise may therefore go completely undetected.

Although a change in wave heights will cause changes to beach profiles, the long-term evolution of the shoreline is almost always linked to changes in the longshore transport of beach sediments or, more precisely, the changes in transport from point to point along the coast. The longshore transport does depend on wave height, but more crucially on wave direction. The former influence, in the long term, can only increase or decrease the rate at which the coastline is eroding or accreting. However, a change in the "average" wave direction will often cause a change in the present trends of erosion and accretion (affecting both rates and patterns). At some locations, it has been found that erosion problems have recently occurred on stretches of coastline which have been stable or accreting for many years.

Impact on beaches in Shetland

The majority of beach units within the Shetland Islands are in the form of pocket or bayhead type beaches. The planshape of such beaches does not change dramatically as incident wave conditions in the nearshore zone are normally experienced from a relatively narrow wave window due to diffraction and refraction effects. Hence changes in wave direction are unlikely to have as much of an effect as they would do on an open, straight coast. There is little longshore sediment transport evident as most of these beaches have orientated to a stable position relative to the incident wave conditions with no long term nett drift occurring. Hence a change in wave heights (of the magnitude likely to be experienced) will have no obvious effect on longshore transport processes. Research into the influence of sea level rise on pocket beaches (Diserens et al, 1992) also concluded that there was no clear linkage between sea level rise and the position of the high water line. However, the tidal range around the coast of Shetland is much lower than that experienced around much of the British Isles. Slight changes in mean sea level may have a greater impact upon the coastline of Shetland than would be experienced on coastlines with a larger tidal range. Where tidal ranges are low, beach units tend to be in a more stable dynamic equilibrium state. Hence, minor changes, such as in sea level, may be more noticeable on such coastlines. For instance, slight increases in mean sea level may cause minor alterations in the diffraction/refraction of wave conditions as they approach the shoreline causing a redistribution of sediment within a particular beach unit. The locations where such effects could be most obvious are at features such as St Ninian's tombolo where minor changes in the incident wave climate could produce a redistribution of the beach material within the system and at worst result in a permanent breach of the feature. The response of such a system will depend critically upon the amount of sediment available.

Of greater impact upon the beaches of Shetland is likely to be either an increase in extreme water levels or in the magnitude or frequency of storm conditions. Virtually all of the beach systems suffer from storm damage at present and any increase in storm frequency or magnitude will result in an increase in backshore erosion. This will be particularly severe upon beach areas where there is little width between the high water mark and the frontal dunes/machair or coastal edge (virtually every beach in Shetland). This form of erosional response will occur along all the sand beach/dune or sand beach/machair systems in

Shetland, e.g. as for example at Quendale, where there is no protection provided by a shingle or cobble storm beach. On beaches where a shingle upper beach (or shingle storm beach) does occur this provides much more protection to the coastal edge from wave attack. However, landward retreat still occurs by rollover where the shingle material is progressively transferred from the shore face, pushed over the crest and onto the back face hence causing landward retreat. The average rate of retreat is approximately proportional to sea level rise and the gradient of the shoreface. Where there is sufficient volume of shingle material the crest of the shingle beach will increase in elevation to accommodate sea level rise. However, if beach material is sparse, any increase in elevation is at the expense of the width of the shingle ridge which would therefore reduce the degree of protection to the coastal edge. Sea level will not proceed at such a rate that overstepping of beaches occurs.

Cliff erosion is still occurring along much of cliffed coastline in the Shetland Islands. This is due to the long term submergence of the Shetland Islands. Hence, there are no wave cut platforms to dissipate the severe wave conditions which propagate close in to the shoreline along the outer edges of these islands. Increases in the frequency or magnitude of storm events will cause an increase in cliff erosion but due to the low erosion rates experienced any such change are unlikely to be apparent.

The extent of coastal edge retreat will vary all along this coastline due to a whole range of interrelating factors such as orientation, degree of shelter by land formations, immediate bathymetry etc. Due to the lack of available beach material, particularly that "stored" in the immediate hinterland, changes in the climate may be apparent upon the beach areas of these islands. However, as there will be no sudden change in sea level or wave climates, such changes will be gradual, with the coastal regime gradually evolving in response to them.

6.3.2 Impacts on man-made defences

General

A study into the effects of sea level rise on coastal structures was carried out by Townend (1994). This showed that the effect of sea level rise on design parameters such as armour weight and run-up depended very much upon the location of the structure in the surf zone and whether waves were breaking or non-breaking at the structure. For instance with breaking waves rock armour weight requires an increase of over 100% for an increase in water depth of only 10%. However, in shallow water where waves are not breaking there is a slight reduction in the required armour weight and in the level of run-up with increases in sea level due to reduced wave shoaling. The effect of sea level rise will always cause an increase in the overtopping of defences irrespective of wave condition.

Possibly of greater importance in the design of coastal structures such as breakwaters and seawalls is the impact of increased storm activity. For example, the size of stable rock armouring on a revetment or breakwater depends on the cube of the design wave height. An increase in extreme wave heights of only 1% each year could, in a decade, lead to a requirement for armour unit weights to be some 38% heavier to achieve the same degree of safety.

In most situations, defences first fail "functionally", allowing erosion or flooding of the land behind. Occasionally, however a defence will suddenly fail "structurally", leading to a much greater danger to life and property, for example the collapse of the seawall at Towyn in North Wales. In most cases, the failure of defences results from a combination of factors, e.g. low beach levels, a high tide and large waves from a limited directional sector. A gradual change in the probability of occurrence of just one of these parameters may therefore not be apparent for many years.

Impact on man-made defences in Shetland

Little coastal defence work has been conducted within Cell 11. It is unlikely that there will be any noticeable increase in the occurrence of damage to the present defence structures other than that due to natural ongoing deterioration.

The most apparent response to changes in either sea level, or increases in the magnitude or frequency of storm conditions, will be an increase in the occurrence and rate of overtopping of defences. Only where defences are backed by properties will this be significant. Given that the only major defences occur at Lerwick, which is in a relatively sheltered location and experiences severe storm waves from only a narrow direction sector, it is debatable whether this is likely to be a major problem.

6.3.3 Other effects

There are a number of other climatic factors which may affect the coastline evolution and hence management techniques. Two of these are discussed below. In each case little is known of the extent of any variations in these climatic factors and whether these are of significance in managing the coast.

Rainfall

There is variation in the rainfall occurring in the UK. In the south of England an oscillation of about 40 years period has been observed. A similar oscillation has apparently been recorded by Stirling University when investigating River Tay flooding. As rainfall increases, a number of effects are likely to occur at the coastline:

- De-stabilisation of soft cliffs

  Cliff falls are usually caused by a combination of marine erosion, e.g. undercutting their front face, and geotechnical problems, e.g. rotational slips. The latter effect is increased by greater rainfall and hence higher run-off, higher water tables etc. Such an increase may occur in Shetland but is unlikely to be noticeable.

- Increased river flows

  In many parts of the world, rivers still bring large quantities of sand and gravel to the coast, again providing fresh supply. Increased river flows would increase the capacity of the river to transport sediment. There are no river systems supplying a significant amount of beach material in the Shetlands. However, streams which pass through dune or machair systems can have the effect of recirculating sediment in the hinterland back onto the beach. Increased flows may result in a slight increase in the amount of material recirculated onto the beach.

- Impacts on sand transport on beaches

  In locations where a beach is affected by surface water run-off from land, there are often localised erosion problems, e.g. around outfalls. The frictional resistance of sand is reduced by the water, making it easier to be mobilised by waves and currents. It is therefore likely that increased rainfall will tend to cause localised beach erosion.

- Impacts on dune building
  Wet sand on the foreshore will be much less easily transported by winds than if it is dry, reducing the supply to dunes. However, many dune binding grasses suffer in drought conditions, and are generally healthier in moister climates. This would help to increase the trapping efficiency, and encourage them to colonise new areas more quickly. It is not clear, therefore, whether increased rainfall will assist dune growth or be detrimental to it.

Changes in wind
As well as changes in wind conditions altering waves, discussed earlier, there are other direct effects which may affect the coastline:

- Aeolian sand transport
  Strong winds are capable of transporting large quantities of sand, both along the coastline and perpendicular to it. The former effect can add to, or counteract wave induced longshore drift, but tends to take place a higher levels on the beach profile. Onshore transport by wind typically dominates offshore movement. This is partly because winds blowing over the sea are stronger (less affected by friction) than those blowing offshore.

  A change in wind strengths or directions may also alter existing patterns of sand transport. It is likely that this will be most noticeable in changes in dunes, rather than on the beaches themselves. Much of the dune and machair systems found in the Shetland Islands are suffering from serious wind erosion.

Much of the above discussion on climatic change and its impact on coastal response is based on logical argument rather than well documented case histories.

The impact of climatic change on the coastline of Cell 11 may well be noticeable due to the lack of beach sediments within most of the beach units. However, many of these beaches are remote with minimal present day human influences (apart from quarrying at some sites) and the beaches will respond in a natural manner without impacting seriously on infrastructure or other anthropogenic features. The complexity of the coastal and nearshore zone makes it difficult to predict morphological changes due to the range of interrelating parameters which affect this zone. To identify and quantify the effect on the coastline of changes to any one, or a number of, these parameters would require good quality, long-term data to validate predictive methods and to identify changes in the marine (i.e. hydraulic) climate.

Trying to separate longer-term climate change effects from those caused by "normal" fluctuations in weather is a major challenge. There is a clear need for monitoring of the coastline, not only to understand the processes, but to provide a long-term data-set for future generations trying to deal with the effects of potentially more dramatic climate changes.

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Figures 1-18

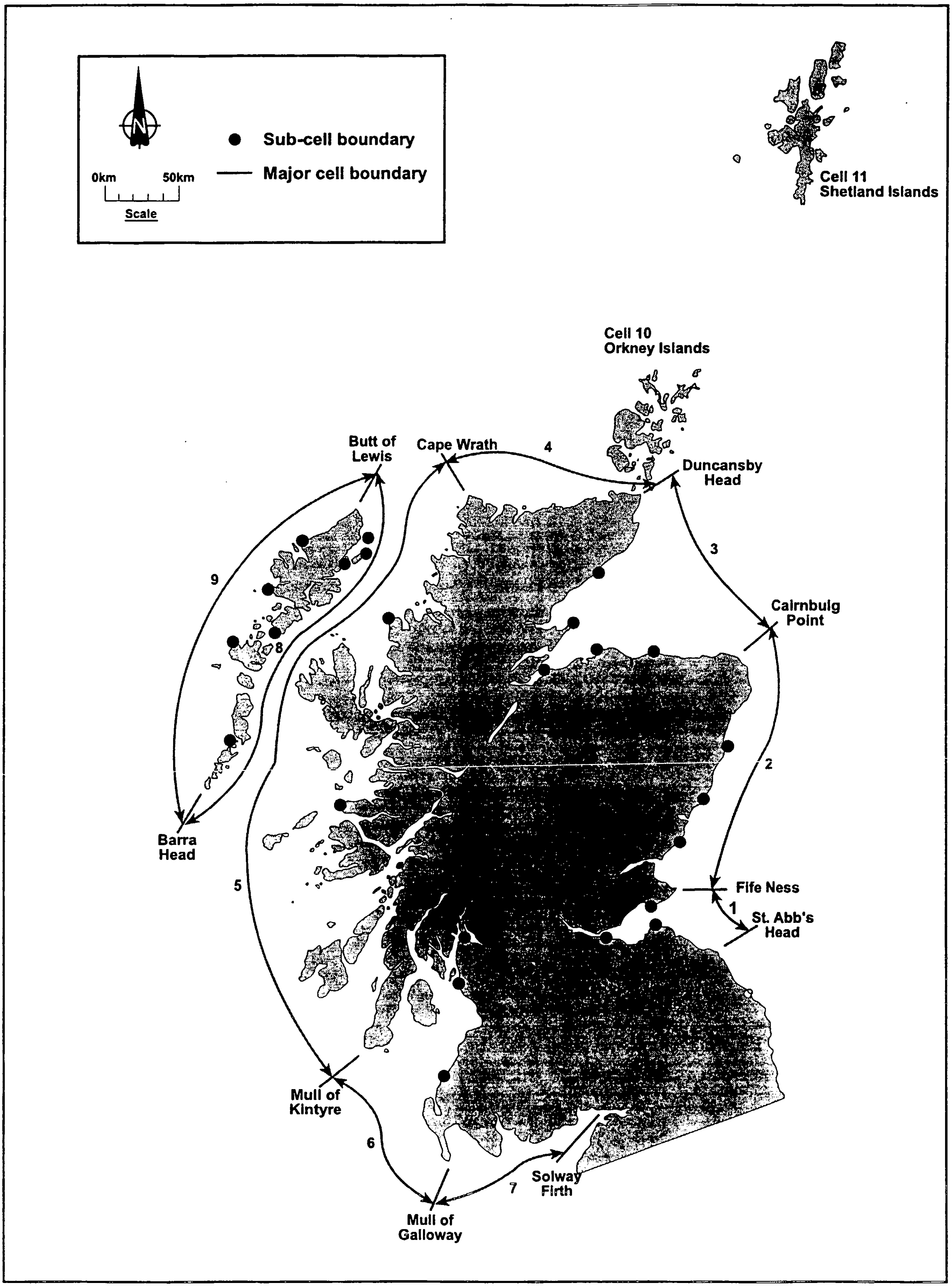


Figure 1 Coastal Cells in Scotland

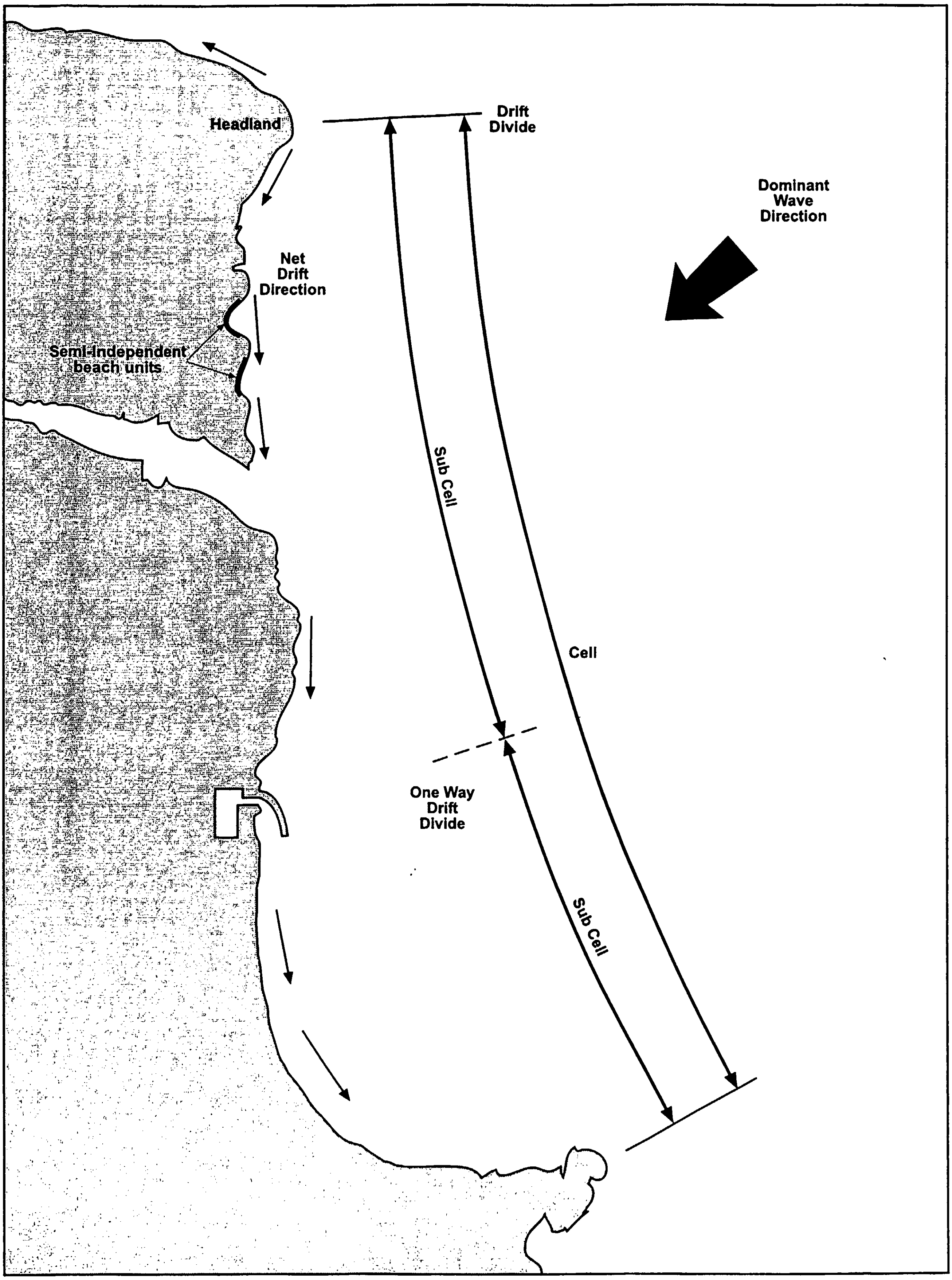


Figure 2 Idealised coastal cell

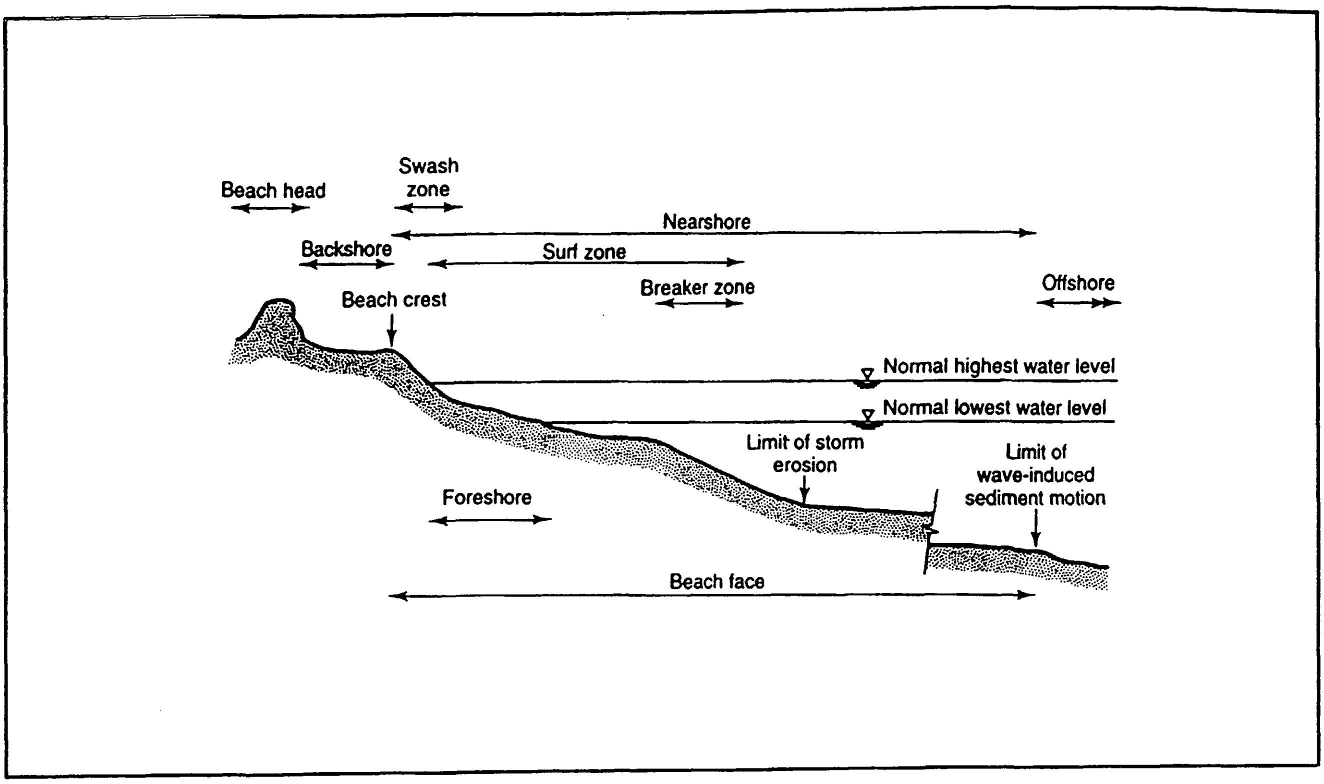


Figure 3 General beach profile and littoral zone

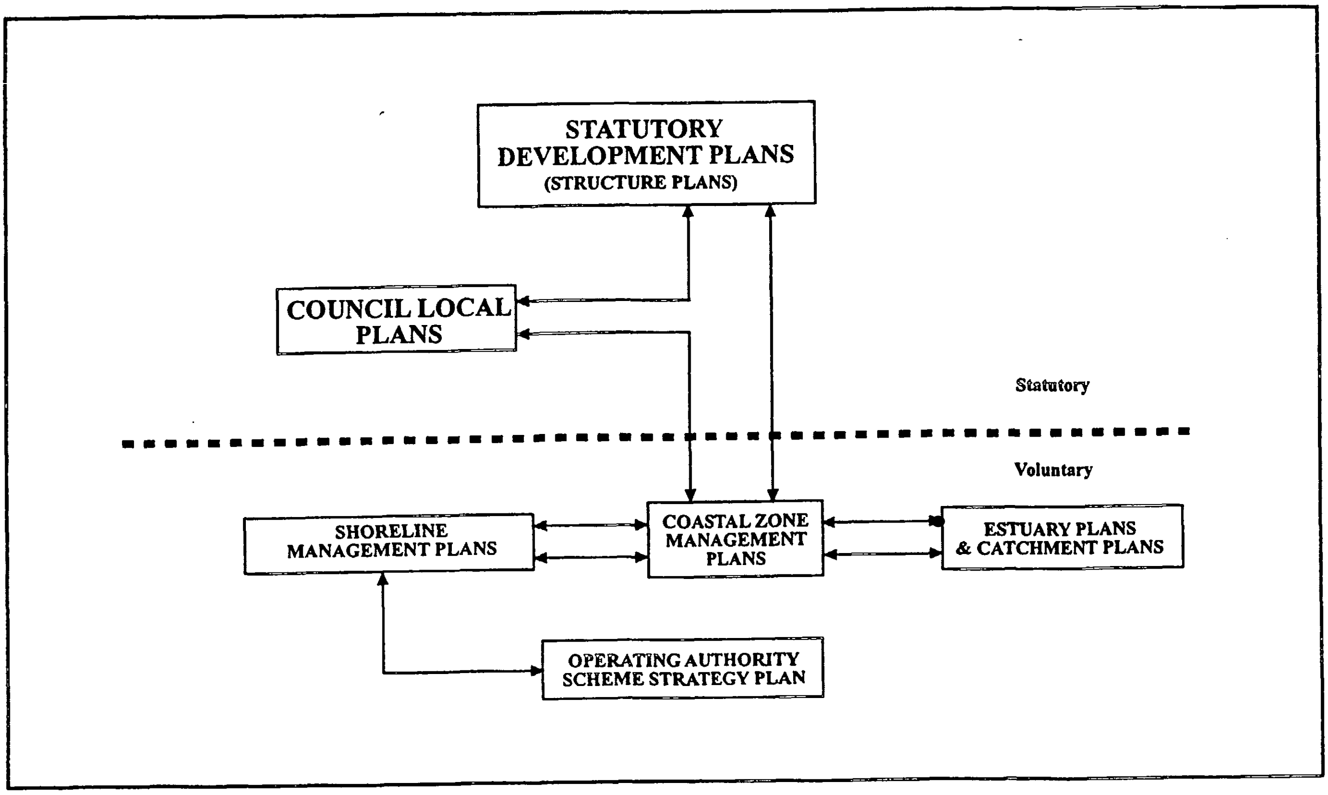


Figure 4 Relationship between coastal initiatives

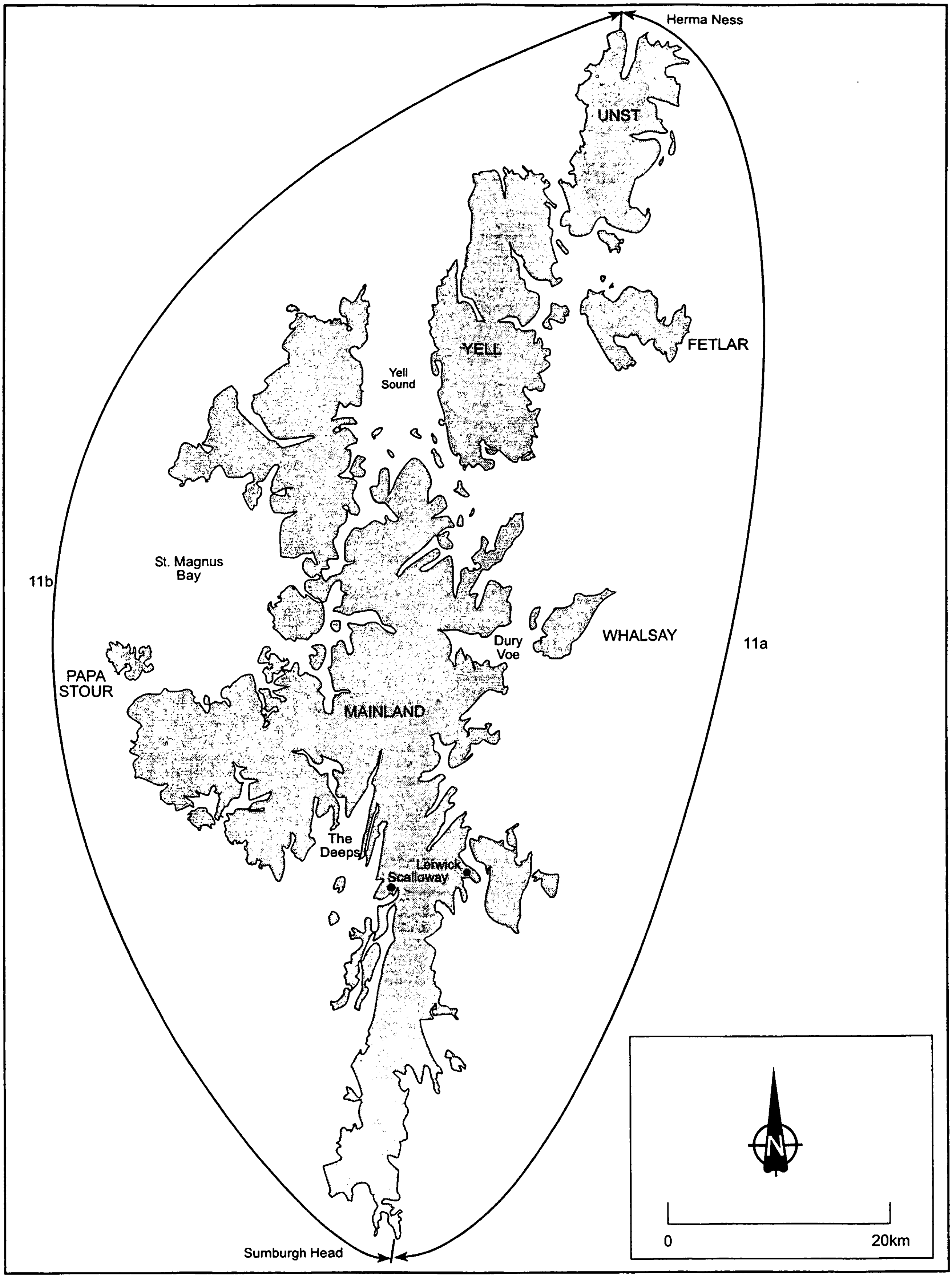


Figure 5 Cell 11 - The Shetland Isles

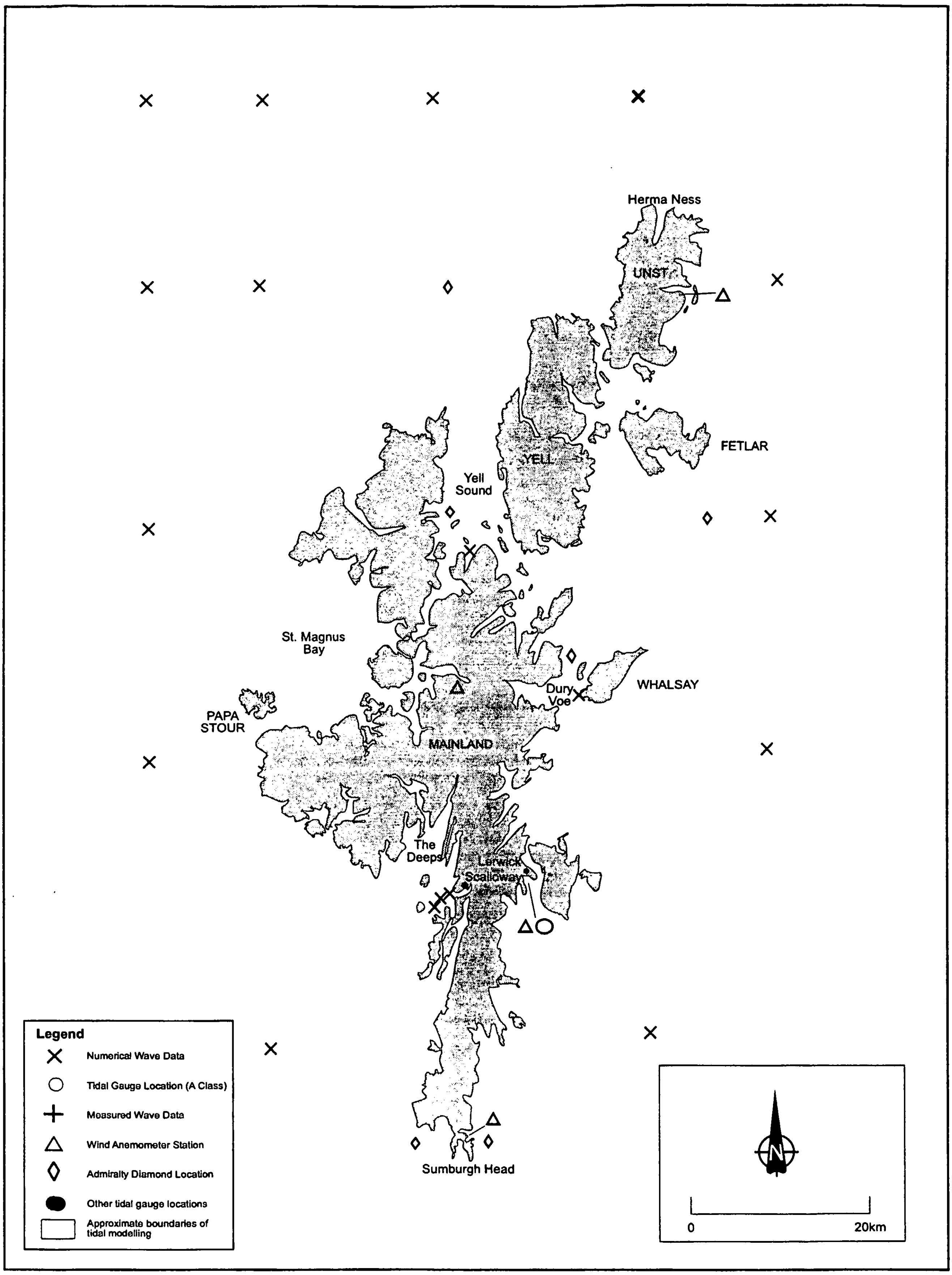
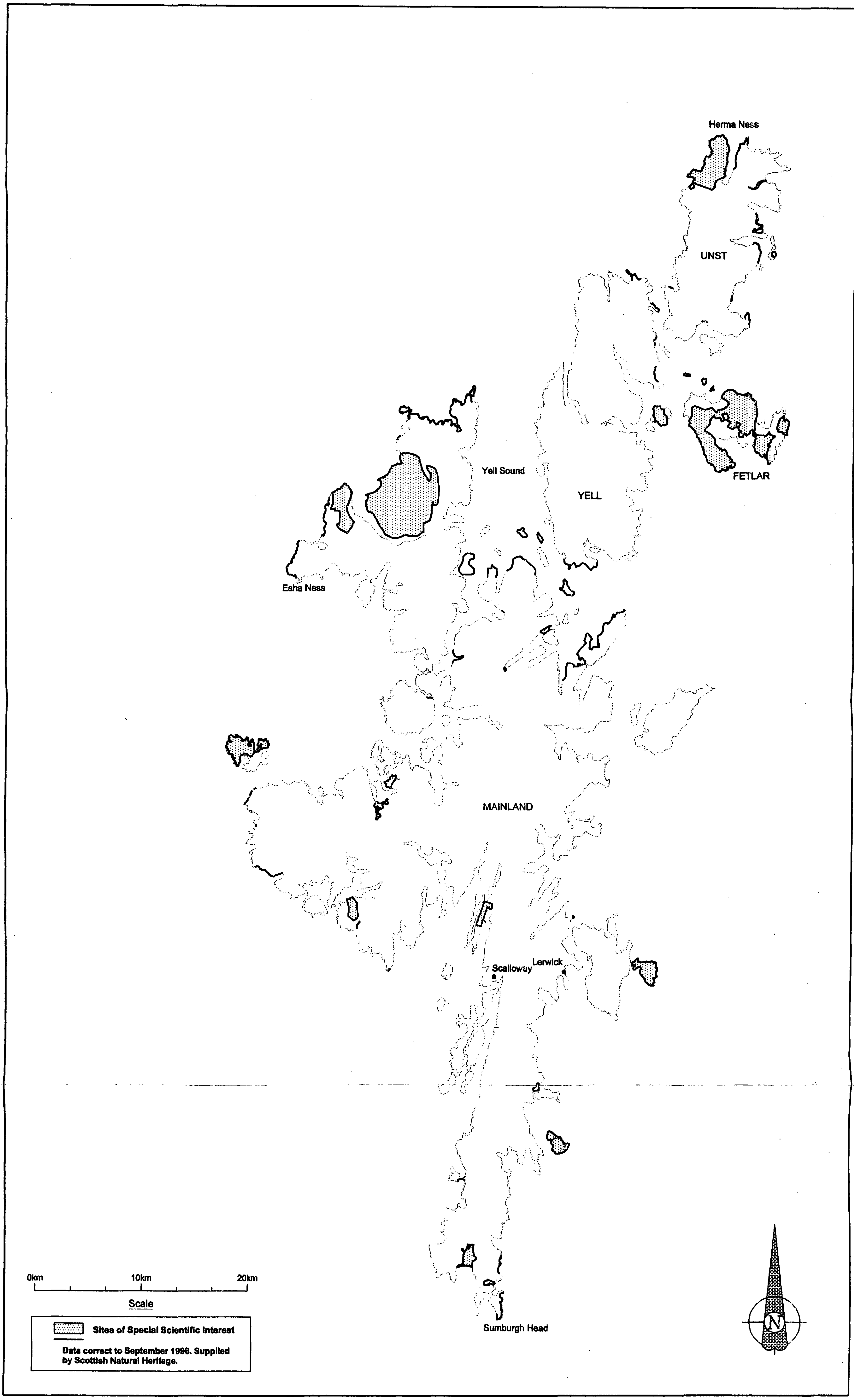


Figure 6 Cell 11 - Location of wind, tidal and wave data

Figure 7 Cell 11 - Location of Sites of Special Scientific Interest



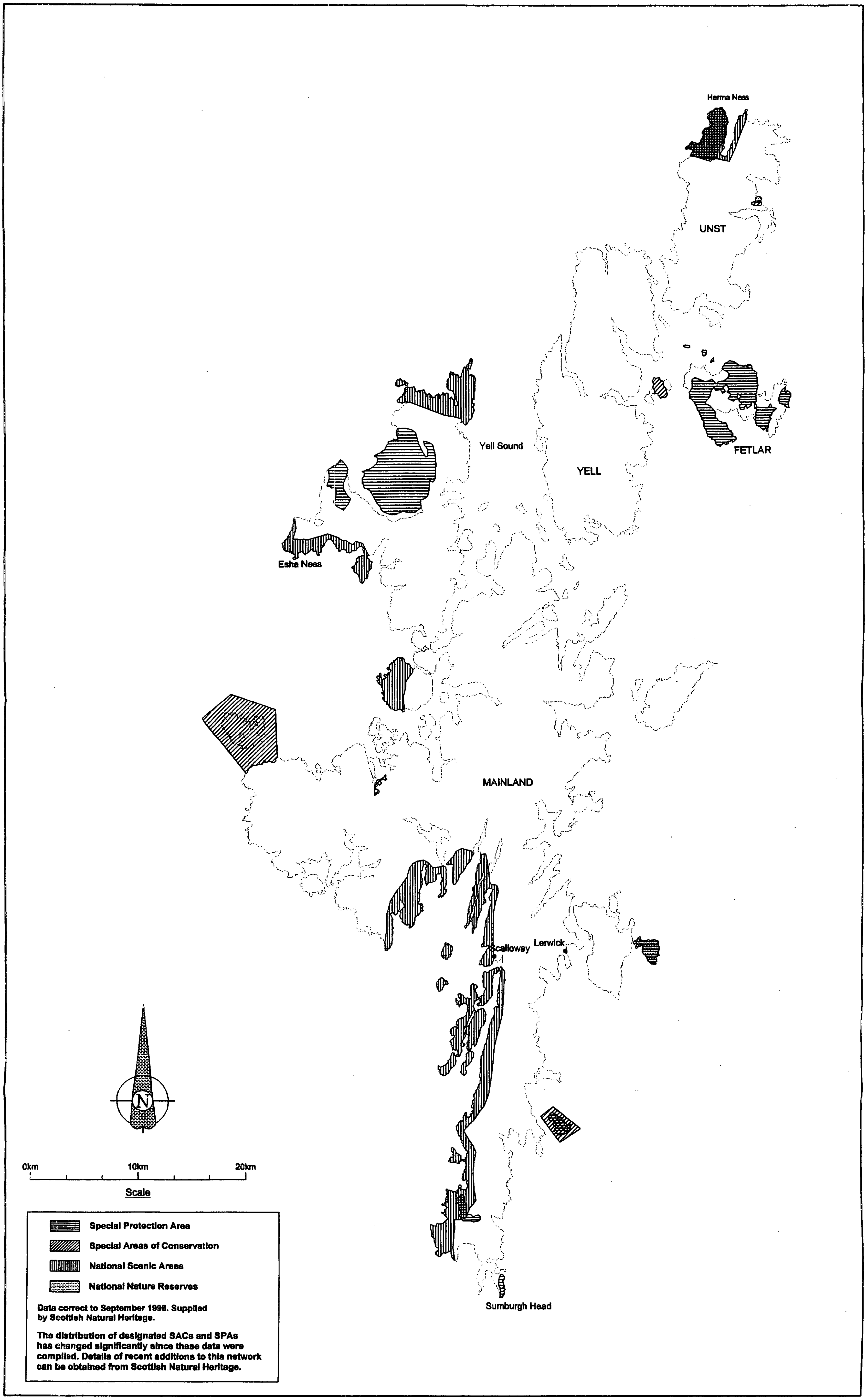


Figure 8 Cell 11 - Location of sites of natural heritage importance (other than SSSIs)

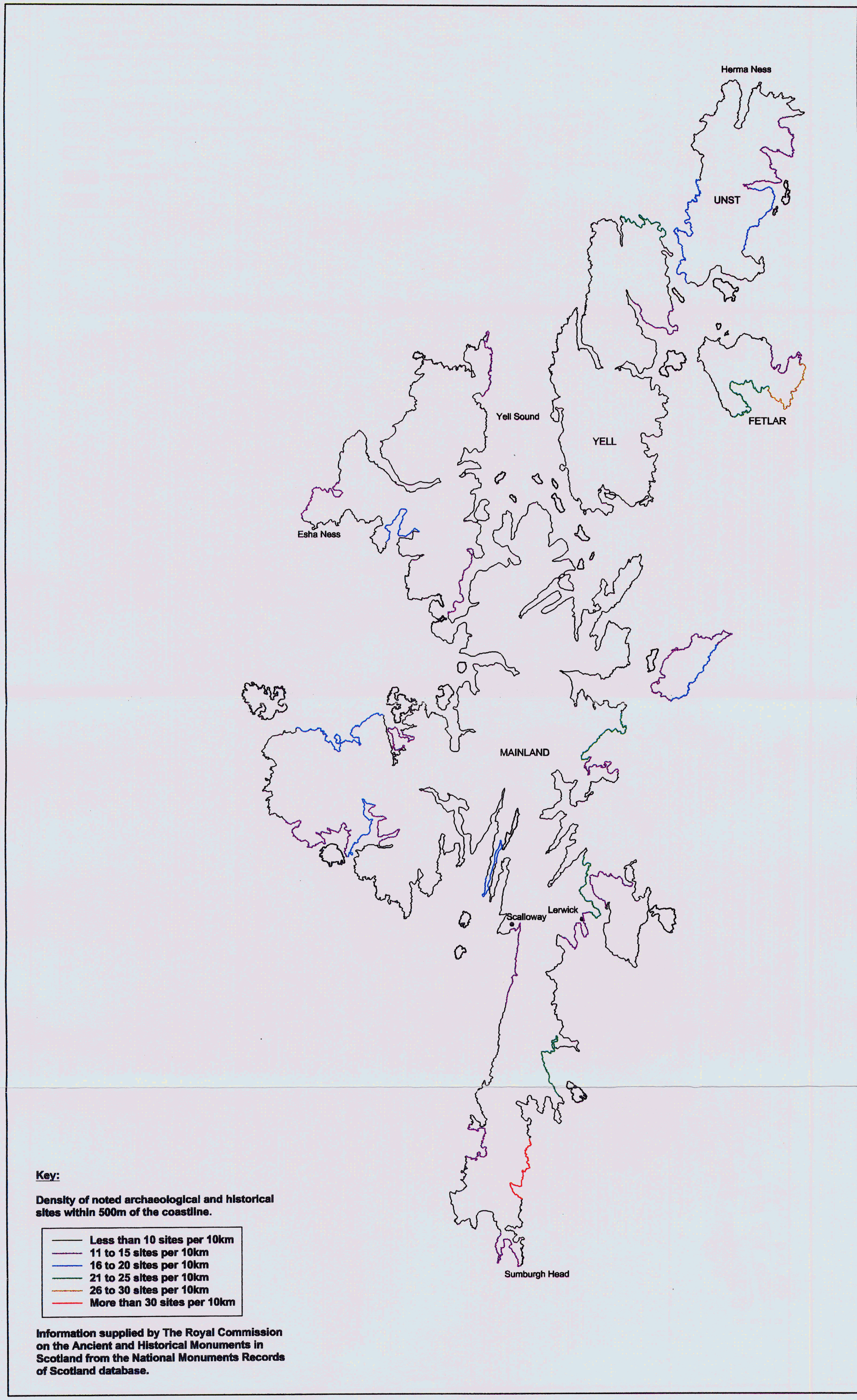
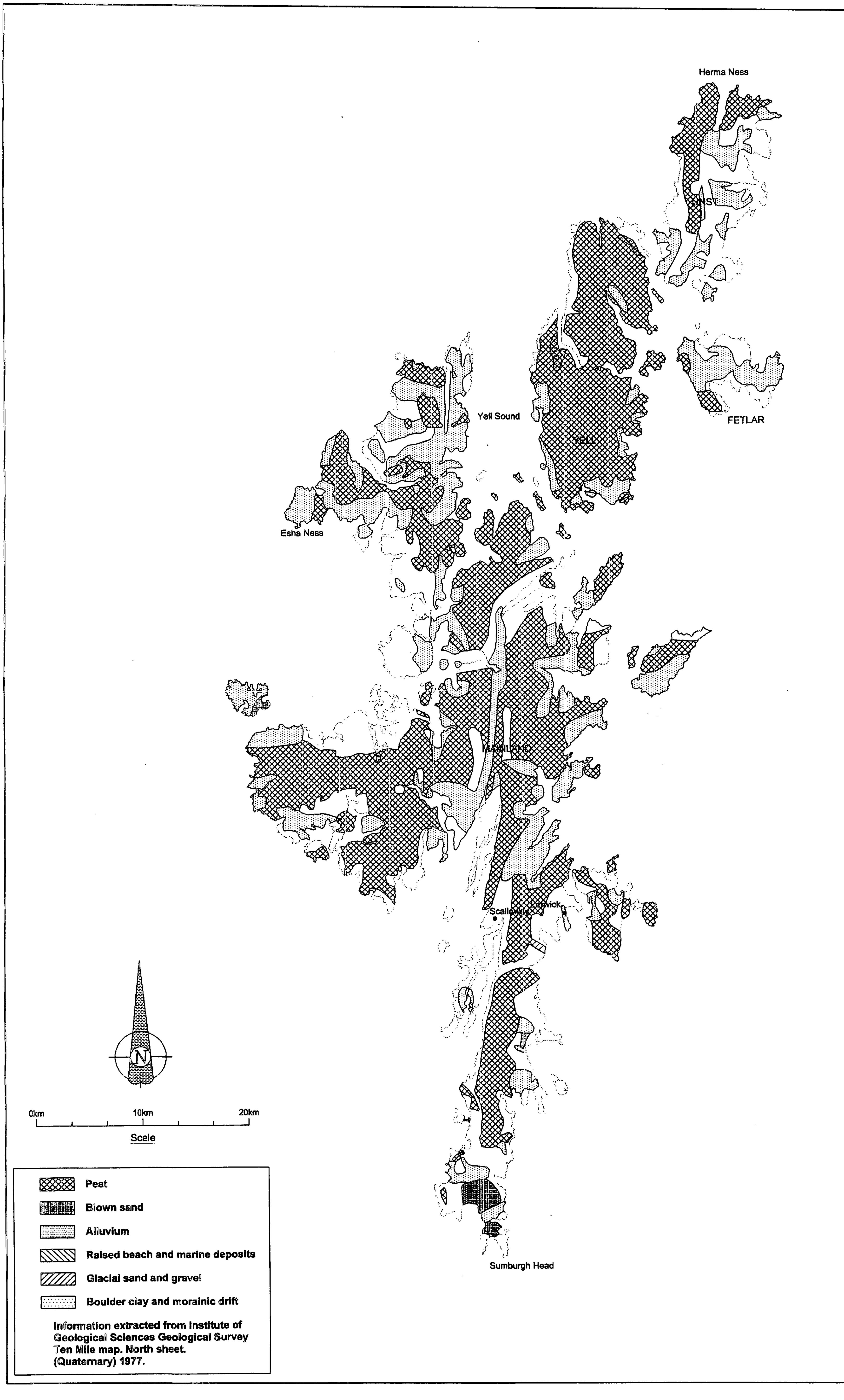


Figure 9 Cell 11 - Density of noted archaeological and historic sites

Figure 10 Cell 11 - Drift deposits



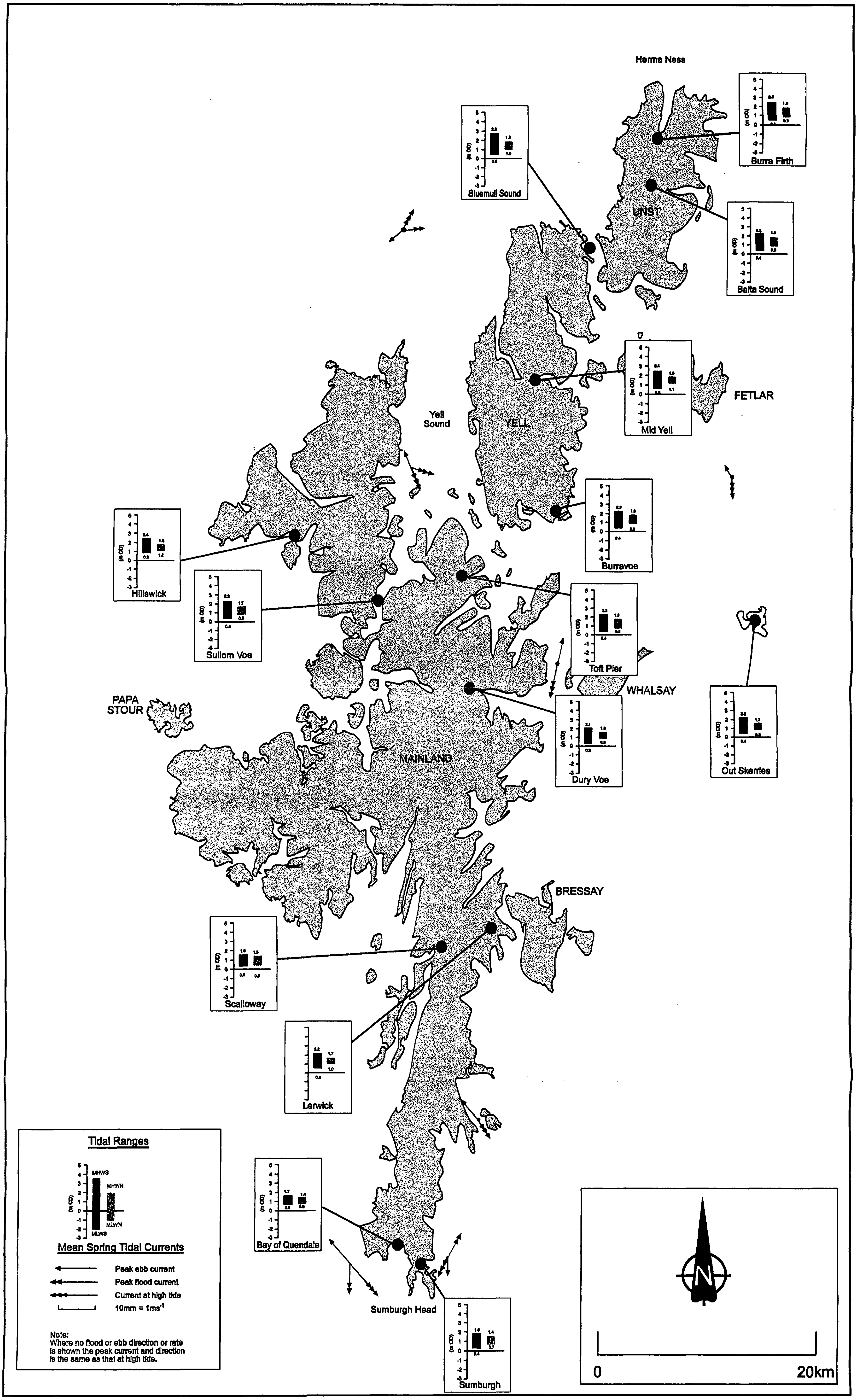


Figure 11 Cell 11 - Tidal levels and current information

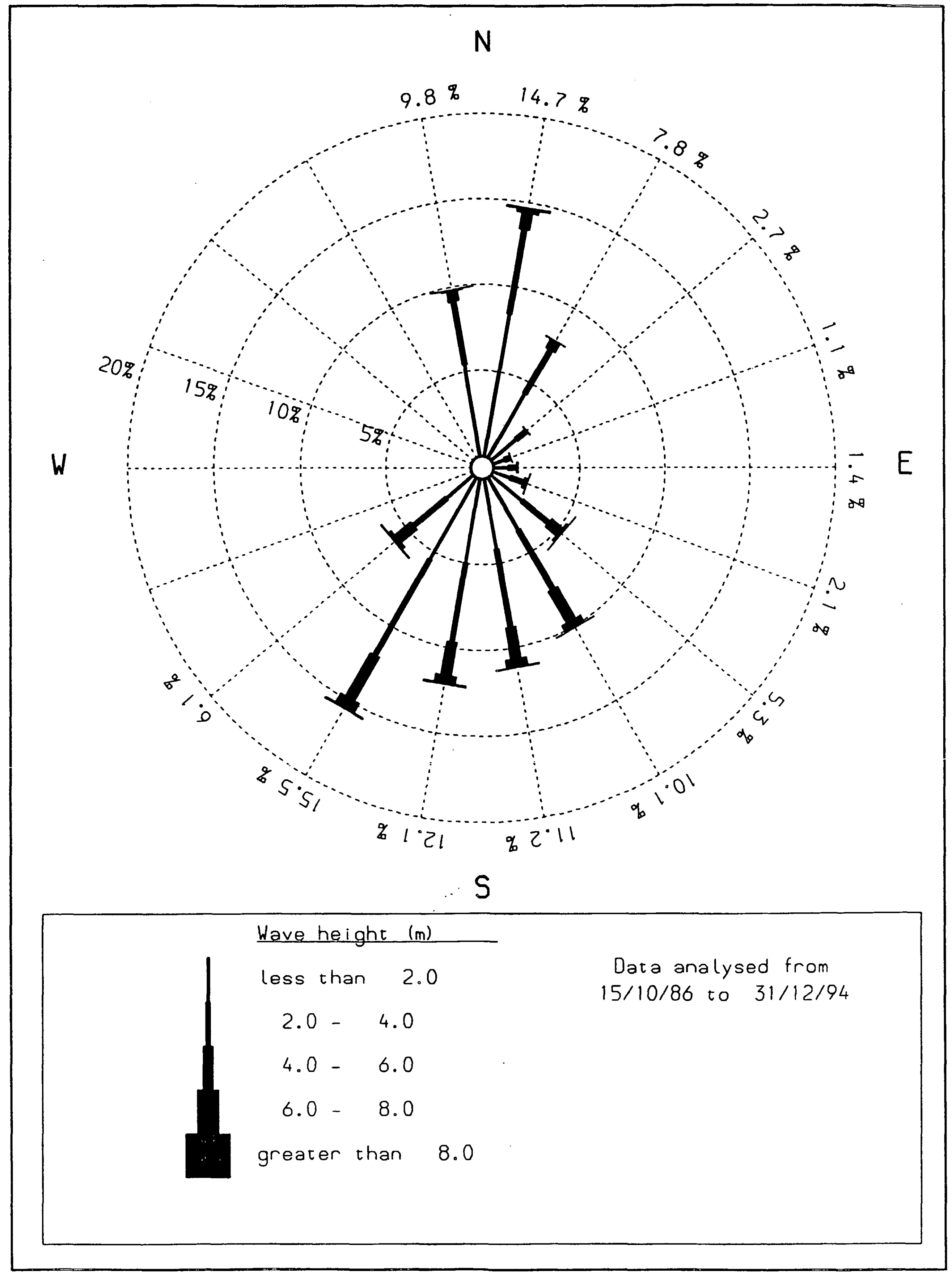


Figure 12 Total offshore wave climate east of Shetland

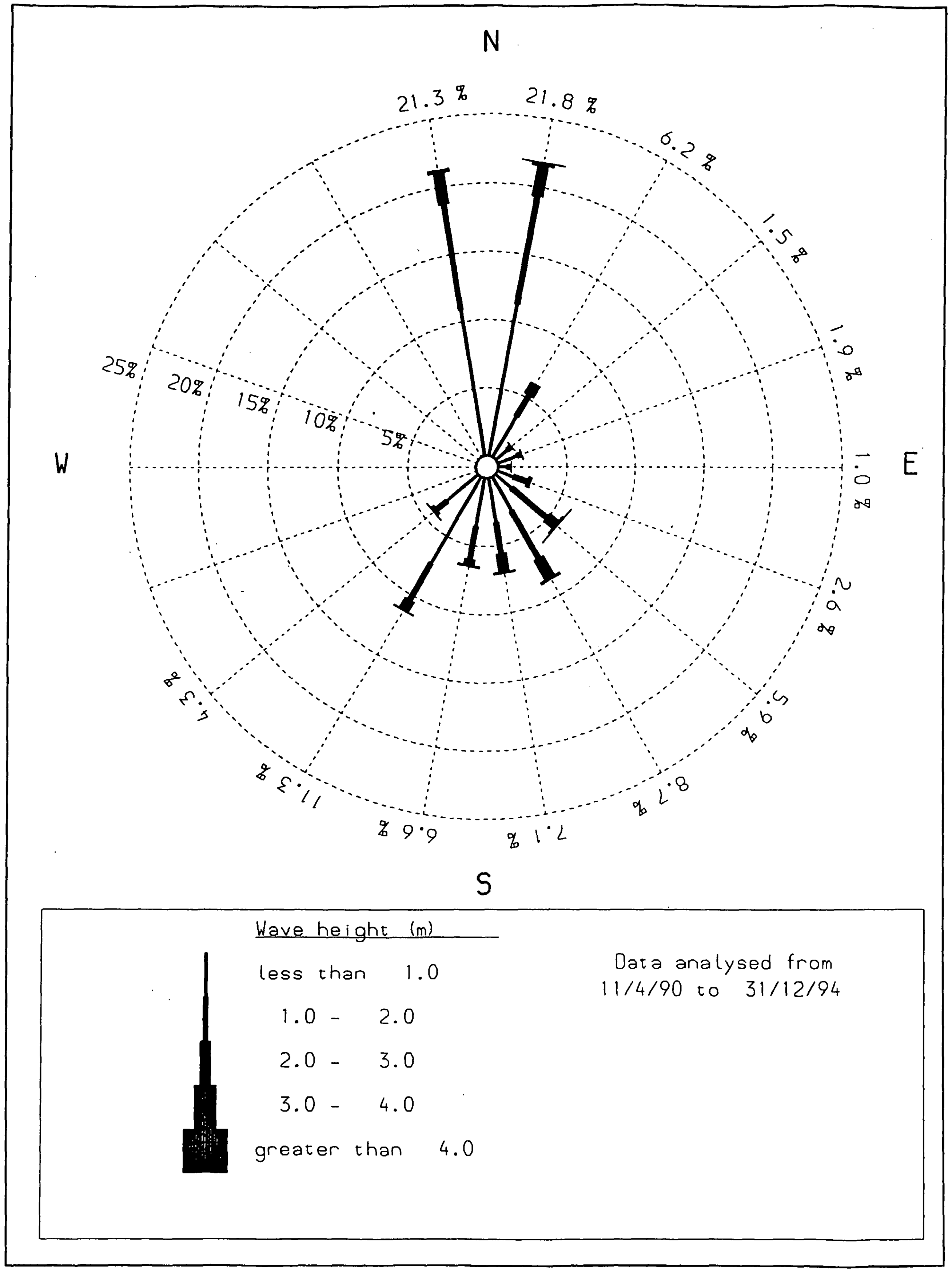
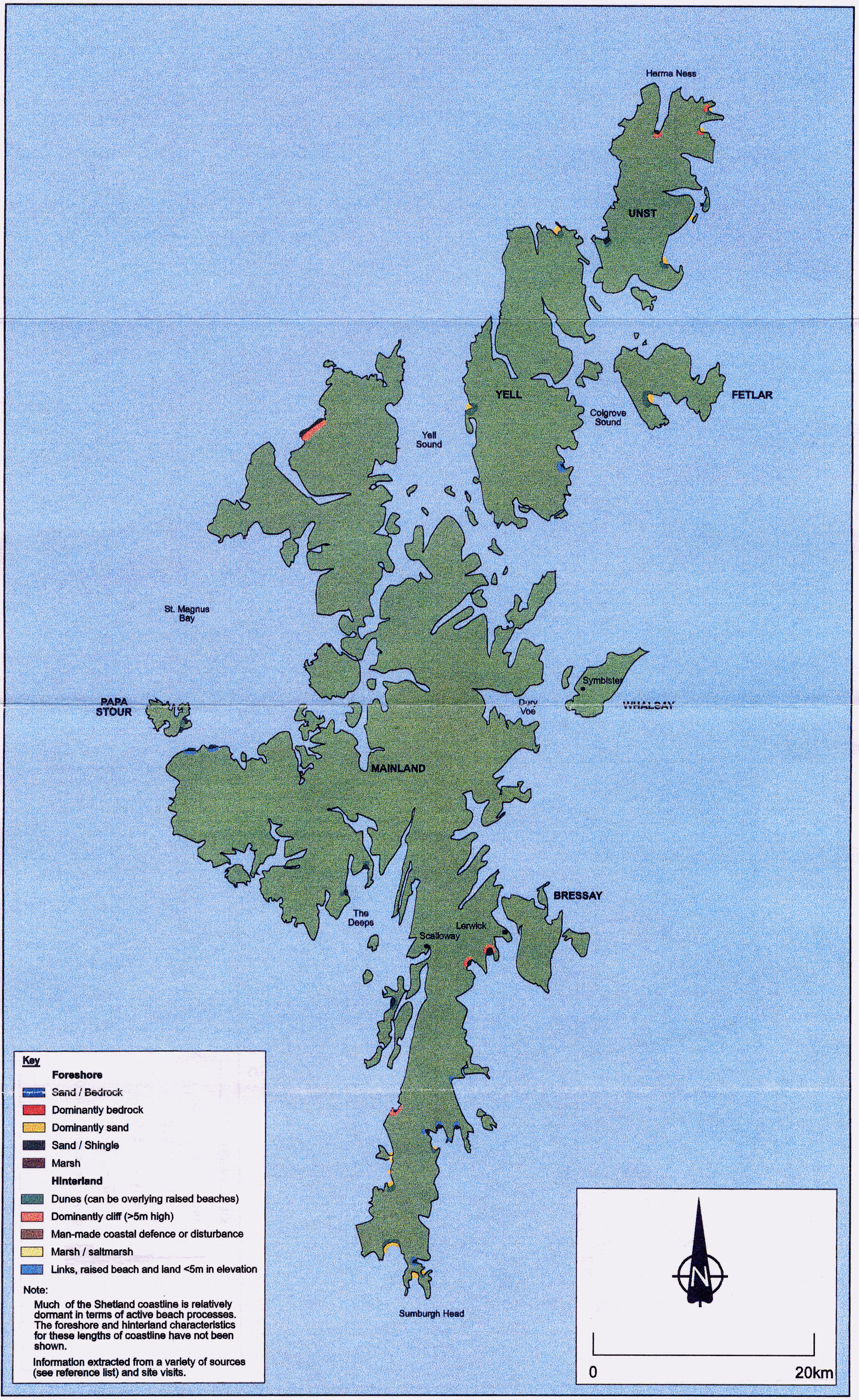


Figure 13 Swell offshore wave climate east of Shetland

Figure 14 Foreshore and hinterland characteristics



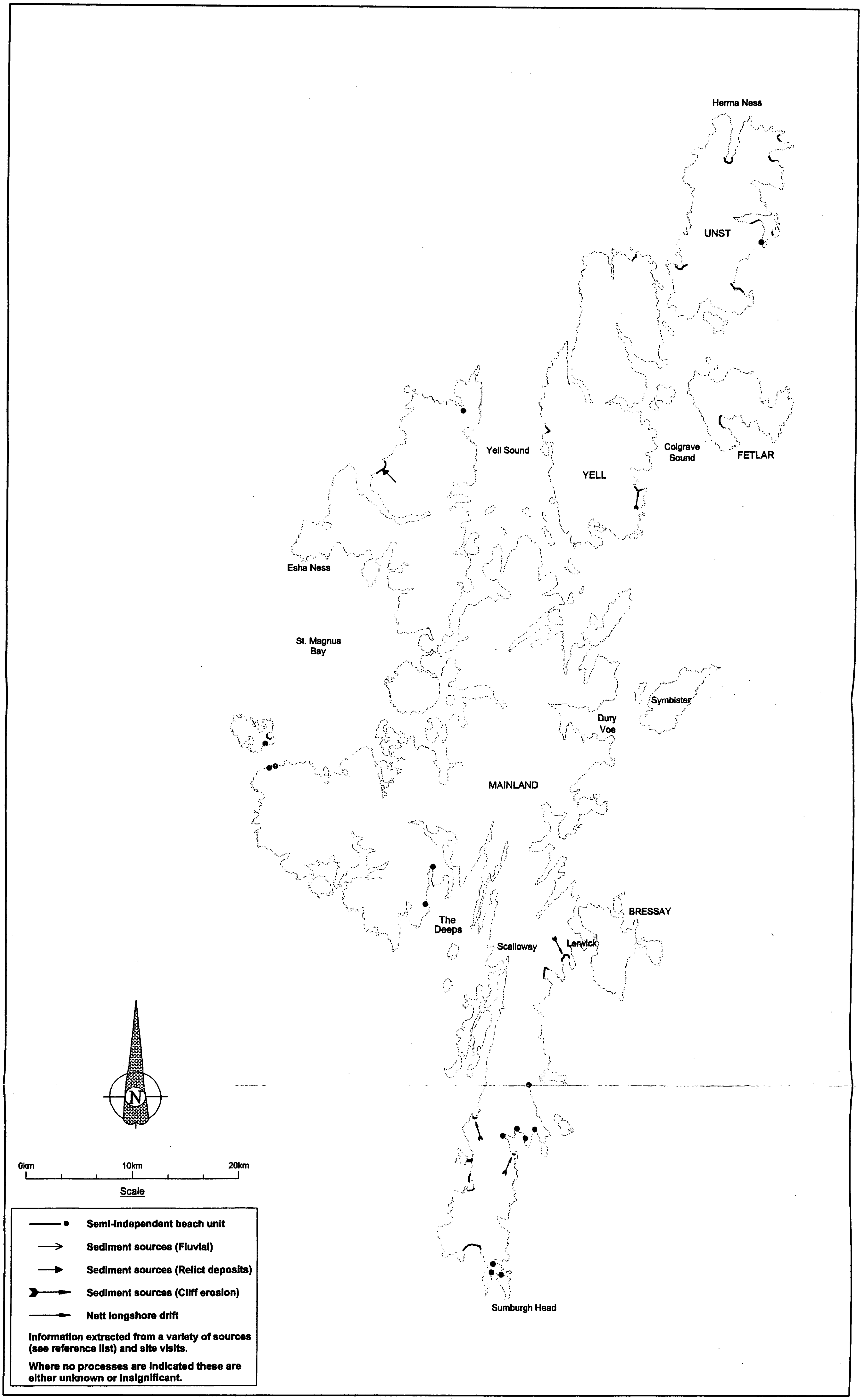


Figure 15 Dominant littoral processes

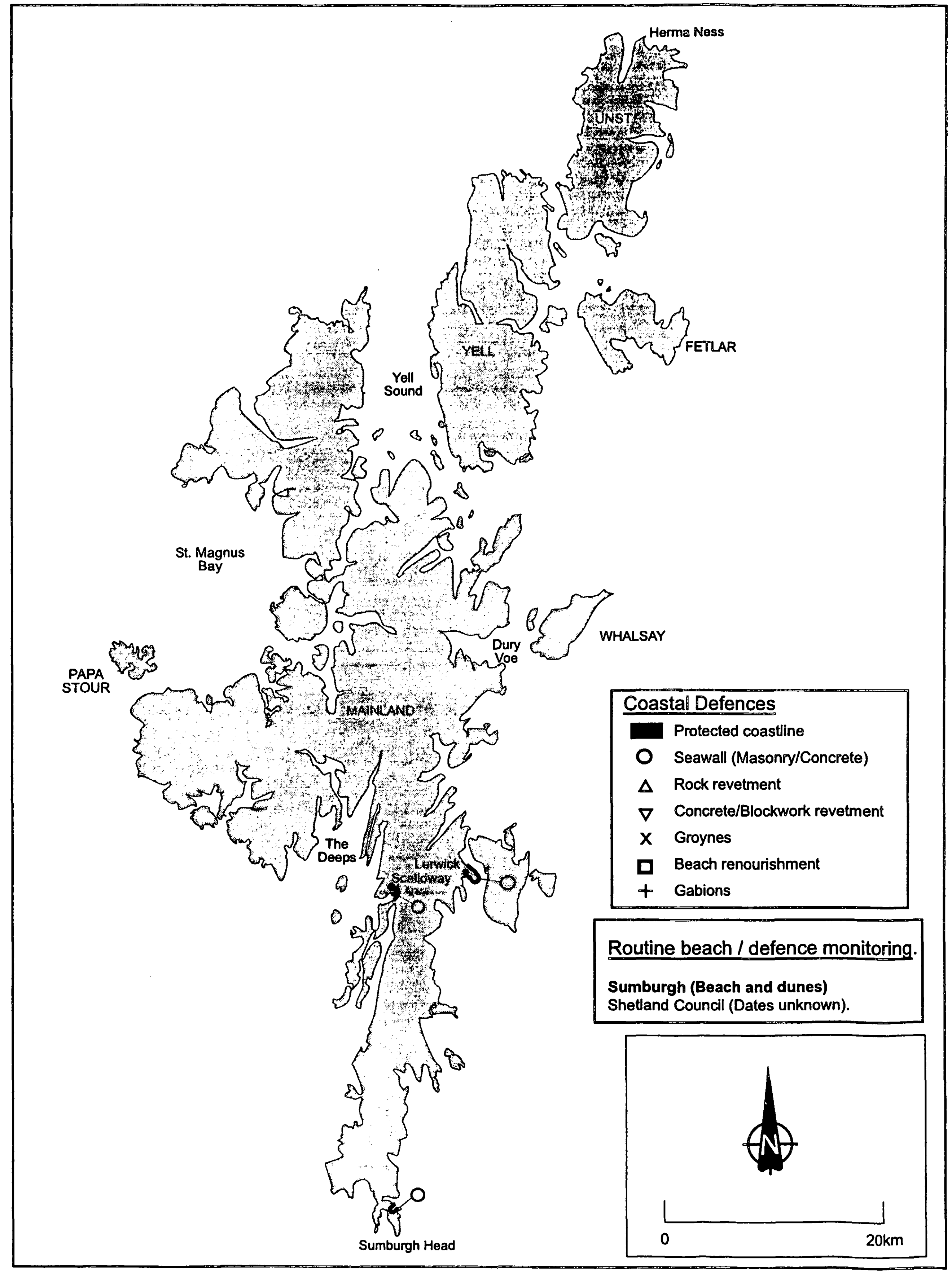


Figure 16 Coastal defence and monitoring

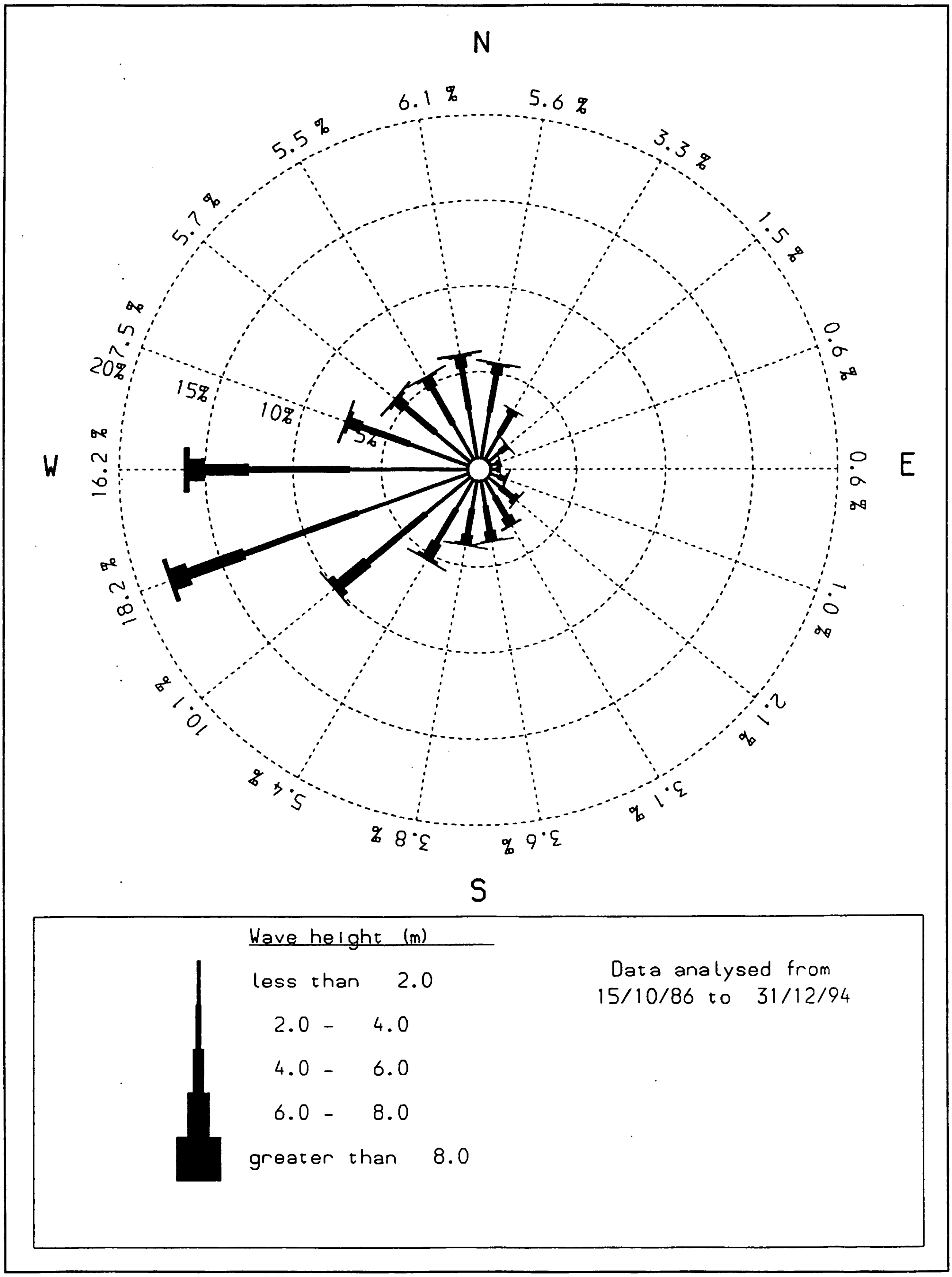


Figure 17 Total offshore wave climate west of Shetland

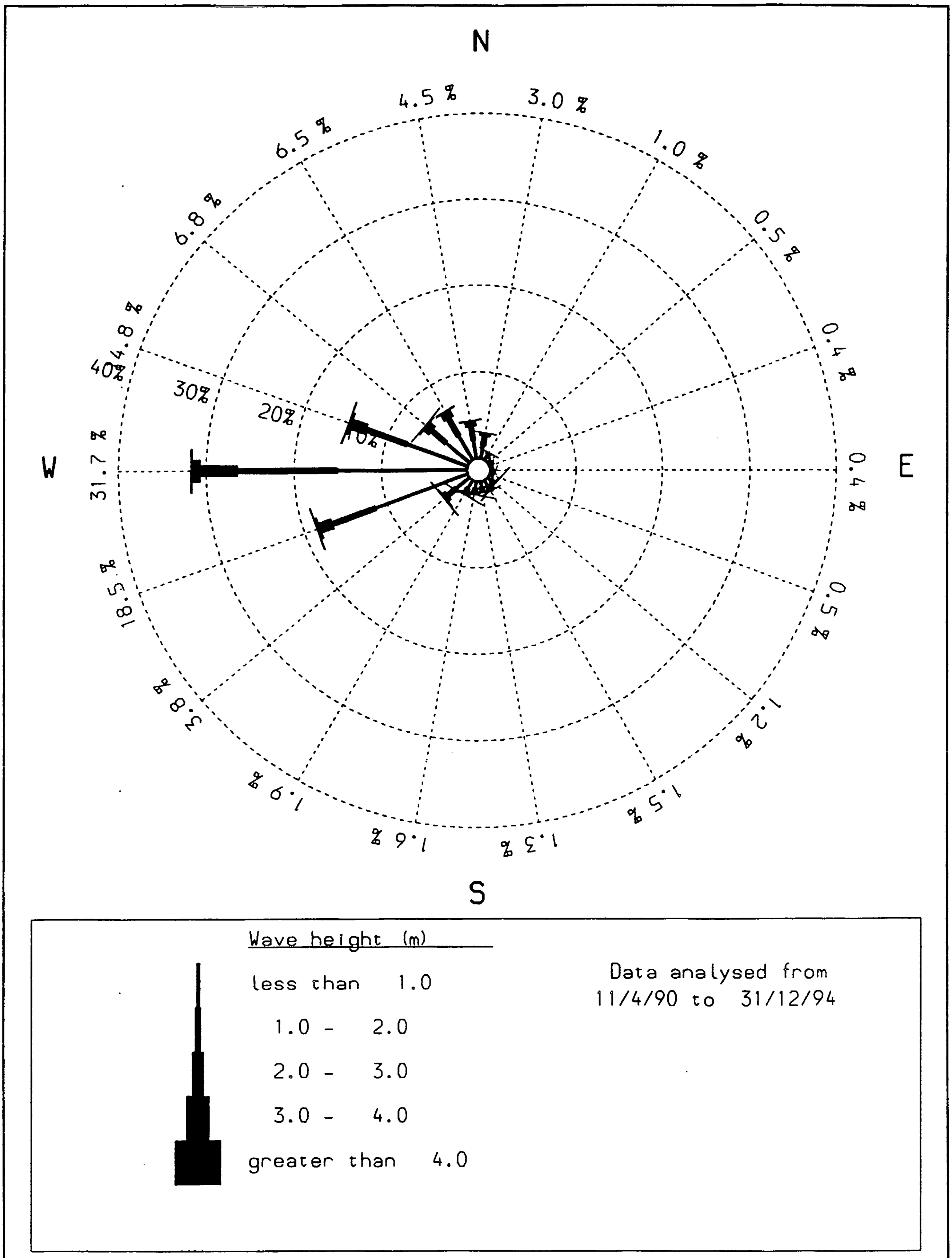


Figure 18 Swell offshore wave climate west of Shetland

Appendix 1 Cell 11 - Details of Sites of Special Scientific Interest

Extracted from the British Oceanographic Data Centre's UKDMAP. Data correct to 1996.

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Sumburgh Head	HU408091	41.3	1984	Geological interest Seabirds breeding
Pool of Virkie	HU398112	32	1983	Tidal flats Open water Marine biological interest Site used by other wintering bird species
Quendale	HU380134	143.4	1968	Sand dunes Machair Wildfowl breeding Site used for wintering wildfowl. Locally important
Lochs of Spiggie & Brow	HU374160	154	1983	Open water Marine biological interest Site used for wintering wildfowl. Locally important
St. Ninian's Tombolo	HU372208	12.6	1987	Geological interest Geomorphological interest
South Whiteness	HU388458	81.8	1986	Saltmarsh Dry grassland Seabirds breeding
Skelda Ness	HU302405	3.3	1989	Geological interest
Culswick Marsh	HU273445	7.9	1983	Open water Fen
Ward of Culswick	HU268463	152.4	1988	Maritime heath Peatland Waders breeding
Lochs of Kirkigarth & Bardister	HU238479	18.1	1983	Open water Site used for wintering wildfowl. Locally important
Fidlar Geo to Watsness	HU190493	18.5	1987	Geological interest
Sel Ayre	HU177540	1.02	1990	Geological interest
Melby	HU168565	6.4	1980	Geological interest
Papa Stour Coast	HU147615	111.8	1990	Geological interest Geomorphological interest

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Papa Stour	HU165610	592.5	1987	Maritime heath Peatland Waders breeding Seabirds breeding
Papa Stour Fish Bed	HU186604	0.4	1990	Geological interest
Ness of Clousta to The Brigs	HU304582	69.9	1989	Geological interest
Muckle Roe Meadows	HU338659	3	1992	Interest not coded
Voxter Voe & Valayre Quarry	HU365697	23.8	1988	Geological interest
Eshaness Coast	HU210790	51.5	1989	Geological interest
Villians of Hamnavoe	HU240824	55.5	1987	Geological interest Geomorphological interest Sea cliff (hard rock)
Tingon	HU255840	584	1988	Open water Peatland Lower plants Waders breeding Seabirds breeding
Ronas Hill - North Roe	HU323855	4906.7	1986	Geological interest Geomorphological interest Open water Montane heath Peatland Terrestrial invertebrates Waders breeding Seabirds breeding
Fugla Ness - North Roe	HU313914	5.1	1986	Geological interest Terrestrial invertebrates Waders breeding Seabirds breeding
Uyea - North Roe Coast	HU344916	264	1991	Geological interest Sea cliff (hard rock) Mammals noted
Ramna Stacks & Gruney	HU380970	10.76	1984	Mammals noted Seabirds breeding
The Ayres of Swinister	HU449273	27.1	1987	Geological interest Geomorphological interest
Laxo Burn	HU445634	0.5	1994	Rare plants
Catfirth	HU437538	0.2	1984	Scrub

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Easter Rova Head	HU474453	3.5	1987	Geological interest
Noss	HU845404	313	1983	Sea cliff (hard rock) Seabirds breeding
Mousa	HU461212	209.8	1983	Coastal lagoon Dry grassland Maritime heath Fen Mammals noted Wildfowl breeding Seabirds breeding
The Cletts, Exnaboe	HU407130	13	1987	Geological interest
Breckon	HP529052	57.9	1983	Open water Sand dunes Machair Dry grassland Scare or rare plants Site used for wintering wildfowl. Locally important
Ness of Cullivoe	HP550025	10.9	1988	Geological interest
Gutcher	HU551997	1.9	1989	Geological interest
North Sandwick	HU550965	5.9	1988	Geological interest
Hascosay	HU553923	165.2	1987	Geological interest Peatland Lower plants Mammals noted Waders breeding Seabirds breeding
Lunda Wick	HP566044	1.2	1987	Geological interest
Tonga Greff	HP585140	19.5	1988	Geological interest
Hermaness	HP605160	980.3	1986	Geological interest Sea cliff (hard rock) Dry grassland Peatland Terrestrial invertebrates Waders breeding Seabirds breeding
Saxa Vord	HP628173	58.9	1988	Sea cliff (hard rock) Seabirds breeding
Norwick	HP650148	6.3	1991	Geological interest

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Norwick Meadows	HP646138	23.2	1984	Sand dunes Wet grassland/grazing marsh Fen Scarce or rare plants Terrestrial invertebrates
Punds to Wick of Hagdale	HP645107	5	1994	Interest not coded
Keen of Hamar	HP645097	51.3	1983	Geological interest Geomorphological interest Other habitats present Scarce or rare plants Other animal/plant groups noted Other bird species breeding Comments: Serpentine vegetation. Metallefeous plant community
Balta	HP660077	16.1	1988	Geological interest Geomorphological interest
Skeo Taing to Clugan	HP647075	15.2	1990	Geological interest
Qui Ness to Pund Stacks	HP622033	2.2	1989	Geological interest
Ham Ness	HP636017	32	1990	Geological interest
Easter Lock	HP598013	6.5	1982	Open water Site used for wintering wildfowl. Nationally important Comments: Whooper swans
Tressa Ness - Colbinskoft	HU615944	14.2	1989	Geological interest
North Fetlar	HU625930	1676.4	1986	Sea cliff (hard rock) Dry grassland Montane heath Mammals noted Waders breeding Seabirds breeding Comments: Non-breeding snowy owl
Virva	HU645920	1.2	1989	Geological interest Sea cliff (hard rock)
Trona Mires	HU670915	153.3	1986	Montane heath Peatland Lower plants Waders breeding Seabirds breeding
Funzie	HU656884	6.8	1991	Geological interest

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Lamb Hoga	HU602897	809.7	1986	Open water Vegetated shingle Dry grassland Maritime heath Montane heath Waders breeding

Appendix 2 Cell 11 - Location of known archaeological and historical sites within 500m of the coastline

Note: This map has not been published within the report but may be consulted (by prior arrangement) by contacting:

Earth Science Group
Advisory Services
Scottish Natural Heritage
2 Anderson Place
EDINBURGH
EH6 5NP

The underlying data are updated regularly by the National Monuments Record of Scotland and are available for inspection there, by prior arrangement.

Appendix 3 Useful addresses

Contact addresses for organisations referred to within the report and other useful contacts.

British Geological Survey (Scotland)
Murchison House
West Mains Road
Edinburgh — Tel: 0131-667 1000
EH9 3LA — Fax: 0131-668 2683

British Geological Survey (Coastal Geology Group)
Kingsley Dunham Centre
Keyworth
Nottingham — Tel: 0115 9363100
NG12 5GG — Fax: 0115 9363200

British Oceanographic Data Centre (BODC)
See Proudman Oceanographic Laboratory

Crown Estate Commission
10 Charlotte Square
Edinburgh — Tel: 0131 2267241
EH2 4DR — Fax: 0131 2201366

Historic Scotland
Longmore House
Salisbury Place
Edinburgh — Tel: 0131 6688600
EH9 1SH — Fax: 0131 6688789

HR Wallingford Ltd
Howbery Park
Wallingford
Oxon — Tel: 01491 835381
OX10 8BA — Fax: 01491 825539

Hydrographic Office (Taunton)
OCM (C)
Admiralty Way
Taunton
Somerset — Tel: 01823 337900
TA1 2DN — Fax: 01823 284077

Institute of Marine Studies
University of St Andrews
St Andrews
Fife — Tel: 01334 462886
KY16 9AJ — Fax: 01334 462921

Institute of Oceanographic Sciences
See Proudman Oceanographic Laboratory

Joint Nature Conservation Committee
Monkstone House
City Road
Peterborough — Tel: 01733 562626
PE1 1JY — Fax: 01733 555948

Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen — Tel: 01224 318611
AB9 2QL — Fax: 01224 311556

Marine Information Advisory Service (MIAS)
See Proudman Oceanographic Laboratory

Metoc plc (Metocean)
Exchange House
Station Road
Liphook
Hampshire — Tel: 01428 727800
GU30 7DW — Fax: 01428 727122

Ministry of Agriculture, Fisheries and Food
(Flood and Coastal Defence Division)
Eastbury House
30-34 Albert Embankment
London — Tel: 0207 238 6742
SE1 7TL — Fax: 0207 238 6665

National Museums of Scotland
c/o Royal Museum of Scotland
Chambers Street
Edinburgh — Tel: 0131-225 7534
EH1 1JF — Fax: 0131-220 4819

Ordnance Survey (Scottish Region)
Grayfield House
5 Bankhead Avenue
Edinburgh — Tel: 0845 605 0505
EH11 4AE

Proudman Oceanographic Laboratory
(British Oceanographic Data Centre, MIAS & Permanent Service for Mean Sea Level)
Bidston Observatory
Birkenhead
Merseyside — Tel: 0151-653 8633
L43 7RA — Fax: 0151-653 6269

Permanent Service for Mean Sea Level (PSMSL)
See Proudman Oceanographic Laboratory

Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS)
John Sinclair House
16 Bernard Terrace
Edinburgh
EH8 9NX
Tel: 0131-662 1456
Fax: 0131-662 1477

Scottish Environment Protection Agency
Erskine Court
The Castle Business Park
Stirling
FK9 4TR
Tel: 01786 457700
Fax: 01786 446885

Scottish Executive (re Coast Protection Act (CPA))
Rural Affairs Department
European Environment and Engineering Unit
Victoria Quay
Edinburgh
EH6 6QQ
Tel: 0131-556 8400

Scottish Executive (re Food and Environment Protection Act (FEPA))
Rural Affairs Department
Pentland House
47 Robbs Loan
Edinburgh
EH14 1TY
Tel: 0131-556 8400

Scottish Executive
Marine Laboratory
PO Box 101
Victoria Road
Torry
Aberdeen
Tel: 01224 876544
Fax: 01224 295511

Scottish Natural Heritage
12 Hope Terrace
Edinburgh
EH9 2AS
Tel: 0131-447 4784
Fax: 0131-446 2277

Scottish Trust for Underwater Archaeology
c/o Department of Archaeology
University of Edinburgh
16-20 George Square
Edinburgh
EH8 9JZ
Tel: 0131-650 2368
Fax: 0131-650 4094

Scottish Tourist Board
23 Ravelston Terrace
Edinburgh
EH4 3EU

Tel: 0131-332 2433
Fax: 0131-343 1513

UK Meteorological Office
Marine Consulting Service
Johnstone House
London Road
Bracknell
RG12 2UR

Tel: 01344 420242
Fax: 01344 854412

UK Offshore Operators Association Ltd (UKOOA)
30 Buckingham Gate
London
SW1E 6NN

Tel: 020 7802 2400
Fax: 020 7802 2401

Appendix 4 Glossary

Abrasion platform	A rock or clay platform which has been worn by the processes of abrasion (i.e. frictional erosion by material transported by wind and waves)
Accretion	The accumulation of (beach) sediment, deposited by natural fluid flow processes
A Class tide gauge	One of a UK network maintained to the highest and most consistent standards
Amplitude	Half of the peak-to-trough range (or height)
Apron	Layer of stone, concrete or other material to protect the toe of a seawall
Armour layer	Protective layer on a breakwater or seawall composed of **armour units**
Armour unit	Large quarried stone or specially shaped concrete block used as primary protection against wave action
Asperities	The three-dimensional irregularities forming the surface of an irregular stone (or rock) subject to wear and rounding during attraction
Astronomical tide	The tidal levels and character which would result from gravitational effects, e.g. of the Earth, Sun and Moon, without any atmospheric influences
Back-rush	The seaward return of water following the **up-rush** of a wave
Backshore	The upper part of the active beach above the normal reach of the tides (high water), but affected by large waves occurring during a high tide
Barrier beach	A sand or shingle bar above high tide, parallel to the coastline and separated from it by a lagoon
Bathymetry	Refers to the spatial variability of levels on the seabed
Beach	A deposit of non-cohesive material (e.g. sand, gravel) situated on the interface between dry land and the sea (or other large expanse of water) and actively "worked" by present-day hydrodynamic processes (i.e. waves, tides and currents) and sometimes by winds
Beach crest	The point representing the limit of high tide storm wave **run-up**
Beach face	From the **beach crest** out to the limit of sediment movement
Beach head	The cliff, dune or seawall forming the landward limit of the active beach
Beach plan shape	The shape of the beach in plan; usually shown as a contour line, combination of contour lines or recognizable features such as beach crest and/or still water line
Beach profile	A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or seawall, extend over the **backshore**, across the **foreshore**, and seaward underwater into the **nearshore** zone

Beach recharge	Supplementing the natural volume of sediment on a beach, using material from elsewhere - also known as beach replenishment/nourishment/feeding
Bed forms	Features on a seabed (e.g. ripples and sand waves) resulting from the movement of sediment over it
Bed load	Sediment transport mode in which individual particles either roll or slide along the seabed as a shallow, mobile layer a few particle diameters deep
Bed shear stress	The way in which waves (or currents) transfer energy to the sea bed
Benefits	The economic value of a scheme, usually measured in terms of the cost of damages avoided by the scheme, or the valuation of perceived amenity or environmental improvements
Berm	(1) On a beach: a nearly horizontal plateau on the **beach face** or **backshore**, formed by the deposition of beach material by wave action or by means of a mechanical plant as part of a **beach recharge** scheme (2) On a structure: a nearly horizontal area, often built to support or key-in an **armour layer**
Boulder	A rounded rock on a beach, greater than 250mm in diameter, larger than a **cobble** - see also **gravel, shingle**
Boundary conditions	Environmental conditions, e.g. waves, currents, drifts, etc. used as boundary input to physical or numerical models
Bound long wave	Long wave directly due to the variation in set-down at the breaker line due to wave groups
Breaching	Failure of the **beach head** allowing flooding by tidal action
Breaker depth	Depth of water, relative to **still water level** at which waves break; also known as **breaking depth** or limiting depth
Breaker index	Maximum ratio of **wave height** to water depth in the surf zone
Breaker zone	The zone within which waves approaching the coastline commence breaking, typically in water depths of between 5 and 10 metres
Breaking	Reduction in wave energy and height in the surf zone due to limited water depth
Breastwork	Vertically-faced or steeply inclined structure usually built with timber and parallel to the shoreline, at or near the **beach crest**, to resist erosion or mitigate against flooding
Bypassing	Moving beach material from the **updrift** to the **downdrift** side of an obstruction to **longshore-drift**
Chart datum	The level to which both tidal levels and water depths are reduced - on most UK charts, this level is that of the predicted lowest **astronomical tide** level (LAT)
Clay	A fine grained, plastic, sediment with a typical grain size less than 0.004mm. Possesses electro-magnetic properties which bind the grains together to give a bulk strength or cohesion
Climate change	Refers to any long-term trend in mean sea level, **wave height**, wind speed, drift rate etc.

Closure depth	The depth at the offshore limit of discernible bathymetric change between surveys.
Coastal cell	See Sediment cell
Coastal defence	General term used to encompass both coast protection against erosion and sea defence against flooding
Coastal forcing	The natural processes which drive coastal hydro- and morpho-dynamics (e.g. winds, waves, tides, etc)
Coastal processes	Collective term covering the action of natural forces on the shoreline, and nearshore seabed
Coastal zone	Some combination of land and sea area, delimited by taking account of one or more elements
Coast protection	Protection of the land from erosion and encroachment by the sea
Cobble	A rounded rock on a beach, with diameter ranging from about 75 to 250mm - see also **boulder, gravel, shingle**
Cohesive sediment	Sediment containing significant proportion of clays, the electromagnetic properties of which cause the sediment to bind together
Conservation	The protection of an area, or particular element within an area, whilst accepting the dynamic nature of the environment and therefore allowing change
Core	(1) A cylindrical sample extracted from a beach or seabed to investigate the types and depths of sediment layers (2) An inner, often much less permeable portion of a breakwater, or barrier beach
Coriolis	Force due to the Earth's rotation, capable of generating currents
Crest	Highest point on a beach face, breakwater or seawall
Cross-shore	Perpendicular to the shoreline
Current	Flow of water
Current-refraction	Process by which wave velocity is affected by a current
Cusp	Seaward bulge, approximately parabolic in shape, in the beach contours. May occur singly, in the lee of an offshore bulk or island, or as one of a number of similar, approximately regularly-spaced features on a long straight beach
Deep water	Water too deep for waves to be affected by the seabed; typically taken as half the **wavelength**, or greater
Deflation	Erosion of dunes by wind action
Depth-limited	Situation in which wave generation (or **wave height**) is limited by water depth
Design wave condition	Usually an extreme wave condition with a specified return period used in the design of coastal works
Detached breakwater	A breakwater without any constructed connection to the shore
Diffraction	Process affecting wave propagation, by which wave energy is radiated normal to the direction of wave propagation into the lee of an island or breakwater

Diffraction coefficient	Ratio of diffracted **wave height** to deep water **wave height**
Diurnal	Literally `of the day', but here meaning having a period of a `tidal day', i.e. about 24.8 hours
Downdrift	In the direction of the nett longshore transport of beach material
Drying beach	That part of the beach which is uncovered by water (e.g. at low tide). Sometimes referred to as `subaerial' beach
Dunes	(1) Accumulations of windblown sand on the **backshore**, usually in the form of small hills or ridges, stabilised by vegetation or control structures (2) A type of bed form indicating significant sediment transport over a sandy seabed
Duration	The length of time a wind blows at a particular speed and from the same direction during the generation of storm waves
Ebb	Period when tide level is falling; often taken to mean the **ebb current** which occurs during this period
Edge waves	Waves which mainly exist shoreward of the breaker line, and propagate along the shore. They are generated by the incident waves, their amplitude is a maximum at the shoreline and diminishes rapidly in a seaward direction
Epifauna	Animals living in the sediment surface or on the surface of other plants or animals
Event	An occurrence meeting specified conditions, e.g. damage, a threshold **wave height** or a threshold water level
Exponential distribution	A model probability distribution
Extreme	The value expected to be exceeded once, on average, in a given (long) period of time
Fetch	Distance over which a wind acts to produce waves - also termed **fetch length**.
Fetch-limited	Situation in which wave energy (or **wave height**) is limited by the size of the wave generation area (**fetch**)
Forecasting	Prediction of conditions expected to occur in the near future, up to about two days ahead
Foreshore	The intertidal area below highest tide level and above lowest tide level
Freeboard	The height of the crest of a structure above the **still water level**
Friction	Process by which energy is lost through shear stress
Friction factor	Factor used to represent the roughness of the sea bed
Frontager	Person or persons owning, and often living in, property immediately landward of the beach
Fully-developed sea	A wave condition which cannot grow further without an increase in wind speed - also fully-arisen sea
GIS	Geographical Information System. A database of information which is geographically orientated, usually with an associated visualization system
Gravel	Beach material, coarser than sand but finer than **pebbles** (2-4mm diameter)

Group velocity	The speed of wave energy propagation. Half the wave **phase velocity** in **deep water**, but virtually the same in **shallow water**
Groyne	Narrow, roughly shore-normal structure built to reduce longshore currents, and/ or to trap and retain beach material. Most groynes are of timber or rock, and extend from a seawall, or the **backshore**, well onto the **foreshore** and rarely even further offshore. In the USA and historically called a **groin**
Groyne bay	The beach compartment between two **groynes**
Gumbel distribution	A model probability distribution, commonly used in wind and water level analysis
Hard defences	General term applied to impermeable coastal defence structures of concrete, timber, steel, masonry etc, which reflect a high proportion of incident wave energy, cf **soft defences**
Hindcasting	In wave prediction, the retrospective forecasting of waves using measured wind information
Historic event analysis	Extreme analysis based on hindcasting typically ten events over a period of 100 years
Incident wave	Wave moving landward
Infauna	Animals living in the sediment
Infragravity waves	Waves with periods above about 30 seconds generated by wave groups breaking in the surf zone
Inshore	Areas where waves are transformed by interaction with the sea bed
Intertidal	The zone between the high and low water marks
Isobath	Line connecting points of equal depth, a seabed contour
Isopachyte	Line connecting points on the seabed with an equal depth of sediment
Joint probability	The probability of two (or more) things occurring together
Joint probability density	Function specifying the joint distribution of two (or more) variables
Joint return period	Average period of time between occurrences of a given joint probability event
JONSWAP spectrum	Wave spectrum typical of growing deep water waves
Limit of storm erosion	A position, typically a maximum water depth of 8 to 10 metres, often identifiable on surveys by a break (i.e. sudden change) in slope of the bed
Littoral	Of or pertaining to the shore
Littoral drift, Littoral transport	The movement of **beach material** in the **littoral zone** by waves and currents. Includes movement parallel (longshore drift) and perpendicular (cross-shore transport) to the shore
Locally generated waves	Waves generated within the immediate vicinity, say within 50km, of the point of interest
Log-normal distribution	A model probability distribution
Long-crested random waves	Random waves with variable heights and periods but a single direction
Longshore	Parallel and close to the coastline

Longshore bar	Bar running approximately parallel to the shoreline
Longshore drift	Movement of (beach) sediments approximately parallel to the coastline
Long waves	Waves with periods above about 30 seconds generated by wave groups breaking in the surf zone
Macro-tidal	Tidal range greater than 4m
Managed landward realignment	The deliberate setting back of the existing line of defence in order to obtain engineering and/or environmental advantages - also referred to as managed retreat
Marginal probability	The probability of a single variable in the context of a joint probability analysis
Marginal return period	The return period of a single variable in the context of a joint probability analysis
Meso-tidal	Tidal range between 2m and 4m
Micro-tidal	Tidal range less than 2m
Morphologically averaged wave condition	A single wave condition producing the same nett longshore drift as a given proportion of the annual wave climate
Mud flat	An area of fine silt usually exposed at low tide but covered at high tide, occurring in sheltered estuaries or behind shingle bars or sand spits
Nearshore	The zone which extends from the **swash zone** to the position marking the start of the **offshore zone**, typically at water depths of the order of 20m
Ness	Roughly triangular promontory of land jutting into the sea, often consisting of mobile material, i.e. a beach form
Numerical modelling	Refers to analysis of coastal processes using computational models
Offshore	The zone beyond the **nearshore zone** where sediment motion induced by waves alone effectively ceases and where the influence of the sea bed on wave action is small in comparison with the effect of wind
Operational	The construction, maintenance and day-to-day activities, associated with beach management
Overtopping	Water carried over the top of a **coastal defence** due to wave **run-up** exceeding the **crest** height
Overwash	The effect of waves **overtopping** a **coastal defence**, often carrying sediment landwards which is then lost to the beach system
Peaks over threshold (POT)	Refers to the maximum value of a variable during each excursion above a threshold value
Pebbles	Beach material usually well-rounded and between about 4mm to 75mm diameter
Persistence of storms	The duration of sea states above some severity threshold (e.g. **wave height**)
Phase velocity	The velocity at which a wave crest propagates, cf **group velocity**
Physical modelling	Refers to the investigation of coastal processes using a scaled model

Pierson-Moskowitz spectrum	Wave spectrum typical of fully-developed deep water waves
Piezometric surface	The level within (or above) a soil stratum at which the pore-pressure is zero
Pocket Beach	A beach, usually small, between two **headlands**
Preservation	Static protection of an area or element, attempting to perpetuate the existence of a given `state'
Probability density function	Function specifying the distribution of a variable
Profile of storms	Refers to the persistence of storms coupled with the rate of change of sea state (e.g. **wave height**) within the storms
Reef	A ridge of rock or other material lying just below the surface of the sea
Reflected wave	That part of an incident wave that is returned (reflected) seaward when a wave impinges on a **beach**, **seawall** or other reflecting surface
Refraction coefficient	Ratio of refracted **wave height** to deep water **wave height**
Refraction (of water waves)	The process by which the direction of a wave moving in **shallow water** at an angle to the contours is changed so that the wave crests tend to become more aligned with those contours
Regular waves	Waves with a single height, period and direction
Residual (water level)	The components of water level not attributable to astronomical effects
Return period	Average period of time between occurrences of a given event
Revetment	A sloping surface of stone, concrete or other material used to protect an embankment, natural coast or shoreline against erosion
Rip current	Jet-like seaward-going current normal to the shoreline associated with wave-induced longshore currents
Risk analysis	Assessment of the total risk due to all possible environmental inputs and all possible mechanisms
Runnel	Channels on a beach, usually running approximately shore-parallel and separated by beach ridges
Run-up, run-down	The upper and lower levels reached by a wave on a beach or coastal structure, relative to **still-water level**
Salient	Coastal formation of beach material developed by wave refraction and diffraction and longshore drift comprising of a bulge in the coastline towards an offshore island or breakwater, but not connected to it as in the case of a **tombolo** - see also **ness, cusp**
Sand	Sediment particles, mainly of quartz, with a diameter of between 0.062mm and 2mm, generally classified as fine, medium, coarse or very coarse
Scatter diagram	A two-dimensional histogram showing the joint probability density of two variables within a data sample
Sea defences	Works to alleviate flooding by the sea
Sea level rise	The long-term trend in mean sea level

Seawall	Solid coastal defence structure built parallel to the coastline
Sediment	Particulate matter derived from rock, minerals or bioclastic debris
Sediment cell	In the context of a strategic approach to coastal management, a length of coastline in which interruptions to the movement of sand or shingle along the beaches or nearshore sea bed do not significantly affect beaches in the adjacent lengths of coastline. Also referred to as a coastal cell
Sediment sink	Point or area at which beach material is irretrievably lost from a coastal cell, such as an estuary, or a deep channel in the seabed
Sediment source	Point or area on a coast from which beach material arises, such as an eroding cliff, or river mouth
Seiche	Standing wave oscillation in an effectively closed body of water
Semi-diurnal	Having a period of half a tidal day, i.e. 12.4 hours
Sequencing of storms	Refers to the temporal distribution of storms and therefore how they are grouped
Shallow water	Water of such depth that surface waves are noticeably affected by bottom topography. Typically this implies a water depth equivalent to less than half the **wave length**
Shingle	A loose term for coarse beach material, a mixture of gravel, pebbles and larger material, often well-rounded and of hard rock, e.g. chert, flint etc.
Shoaling	Decrease in water depth. The transformation of wave profile as they propagate inshore
Shoaling coefficient	Ratio of shoaled **wave height** to deep water **wave height**
Shoreline	One characteristic of the coast. Poorly defined but essentially the interface between land and sea
Shoreline management	The development of strategic, long-term and sustainable coastal defence policy within a **sediment cell**
Shore normal	A line at right-angles to the contours in the surf zone
Short-crested random waves	Random waves with variable heights, periods and directions
Significant wave height	The average height of the highest one third of the waves in a given sea state
Silt	Sediment particles with a grain size between 0.004mm and 0.062mm, i.e. coarser than **clay particles** but finer than **sand**
Soft defences	Usually refers to **beaches** (natural or designed) but may also relate to energy-absorbing beach-control structures, including those constructed of rock, where these are used to control or redirect **coastal processes** rather than opposing or preventing them
Spit	A long narrow accumulation of sand or shingle, lying generally in line with the coast, with one end attached to the land the other projecting into the sea or across the mouth of an estuary - see also **ness**

Standard of service — The adequacy of defence measured in terms of the return period (years) of the event which causes a critical condition (e.g. breaching, overtopping) to be reached

Still-water level (SWL) — Water level that would exist in the absence of waves

Strand line — An accumulation of debris (e.g. seaweed, driftwood and litter) cast up onto a beach, and lying along the limit of wave uprush

Sub-tidal beach — The part of the beach (where it exists) which extends from low water out to the approximate limit of storm erosion. The latter is typically located at a maximum water depth of 8 to 10 metres and is often identifiable on surveys by a break in the slope of the bed

Surf beat — Independent long wave caused by reflection of **bound long wave**

Surf zone — The zone of wave action extending from the water line (which varies with tide, surge, set-up, etc.) out to the most seaward point of the zone (**breaker zone**) at which waves approaching the coastline commence breaking, typically in water depths of between 5 to 10 metres

Surge — Changes in water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and that predicted using harmonic analysis, may be positive or negative

Suspended load — A mode of sediment transport in which the particles are supported, and carried along by the fluid

Swash zone — The zone of wave action on the beach, which moves as water levels vary, extending from the limit of **run-down** to the limit of **run-up**

Swell (waves) — Remotely wind-generated waves. Swell characteristically exhibits a more regular and longer period and has longer crests than locally generated waves

Threshold of motion — The point at which the forces imposed on a sediment particle overcome its inertia and it starts to move

Tidal current — The movement of water associated with the rise and fall of the tides

Tidal range — Vertical difference in high and low water level once decoupled from the water level **residuals**

Tidal wave — The rise and fall in water level due to the passage of the tide

Tide — The periodic rise and fall in the level of the water in oceans and seas; the result of gravitational attraction of the sun and moon

Tides — (1) Highest astronomical tide (HAT), lowest astronomical tide (LAT): the highest and lowest levels, respectively, which can be predicted to occur under average meteorological conditions. These levels will not be reached every year. HAT and LAT are not the extreme levels which can be reached, as storm surges may cause considerably higher and lower levels to occur.

(2) Mean high water springs (MHWS), mean low water springs (MLWS): the height of mean high water springs is the average throughout a year of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest. The height of mean low water springs is the average height obtained by the two successive low waters during the same periods.

(3) Mean high water neaps (MHWN), mean low water neaps (MLWN): the height of mean high water neaps is the average of the heights throughout the year of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is least. The height of mean low water neaps is the average height obtained by the two successive low waters during the same periods.

(4) Mean high water (MHW), mean low water (MLW): for the purpose of this manual, mean high/low water, as shown on Ordnance Survey Maps, is defined as the arithmetic mean of the published values of mean high/low water springs and mean high/low water neaps. This ruling applies to England and Wales. In Scotland the tidal marks shown on Ordnance Survey maps are those of mean high (or low) water springs (MH (or L) WS).

TMA spectrum Wave spectrum typical of growing seas in limited water depths

Tombolo Coastal formation of beach material developed by **refraction, diffraction** and **longshore drift** to form a `neck' connecting a coast to an offshore island or breakwater (see also **salient**)

Updrift The direction opposite to that of the predominant longshore movement of beach material

Up-rush The landward return of water following the **back-rush** of a wave

Water depth Distance between the seabed and the **still water level**

Water level Elevation of **still water level** relative to some datum

Wave celerity The speed of wave propagation

Wave climate The seasonal and annual distribution of **wave height, period** and **direction**

Wave climate atlas Series of maps showing the variability of wave conditions over a long coastline

Wave direction Mean direction of wave energy propagation relative to true North

Wave directional spectrum Distribution of wave energy as a function of wave **frequency** and **direction**

Wave frequency The inverse of **wave period**

Wave frequency spectrum Distribution of wave energy as a function of frequency

Wave generation Growth of wave energy by wind

Wave height	The vertical distance between the trough and the following crest
Wavelength	Straightline distance between two successive wave crests
Wave peak frequency	The inverse of wave peak period
Wave peak period	Wave period at which the spectral energy density is a maximum
Wave period	The time taken for two successive wave crests to pass the same point
Wave rose	Diagram showing the long-term distribution of **wave height** and direction
Wave set-up	Elevation of the water level at the coastline caused by radiation stress gradients in the surf zone
Wave steepness	The ratio of **wave height** to wavelength also known as **sea steepness**
Wave transformation	Change in wave energy due to the action of physical processes
Weibull distribution	A model probability distribution, commonly used in wave analysis
Wind rose	Diagram showing the long-term distribution of wind speed and direction
Wind sea	Wave conditions directly attributable to recent winds, as opposed to swell
Wind set-up	Elevation of the water level over an area directly caused by wind stress on the water surface
Wind stress	The way in which wind transfers energy to the sea surface

The Scottish Office

The Scottish Office commissions applied research to support the formulation, development and evaluation of its policies to improve the quality of the Scottish environment and the life of its people. Research also assists the Scottish Office in meeting its statutory responsibilities.

Historic Scotland

Historic Scotland is an Executive Agency within the Scottish Office.
We discharge the Secretary of State for Scotland's functions in relation to the built heritage - that is, ancient monuments, archaeological sites and landscapes; historic buildings, parks and gardens; and designed landscapes.

We:

- promote the conservation of Scotland's historic buildings and monuments:
  - ∞ directly by looking after the buildings in our care, and
  - ∞ indirectly by compiling a schedule of ancient monuments and a list of historic buildings (both statutory), by providing advice and financial assistance to help conserve them, and, where they cannot be preserved and their recording is no one else's responsibility, by arranging for their survey or excavation;
- promote enjoyment of Scotland's built heritage, in particular by encouraging people to visit the properties in our care;
- advise and educate people on the rich heritage of Scotland's rural, urban and industrial landscape and its many ancient monuments and buildings.

Our aim is to protect Scotland's built heritage for the benefit of present and future generations, and to enhance its understanding and enjoyment.

Scottish Natural Heritage

Scottish Natural Heritage is an independent body established by Parliament in 1992, responsible to the Secretary of State for Scotland. Our task is to secure the conservation and enhancement of Scotland's unique and precious natural heritage - the wildlife, the habitats, the landscapes and the seascapes which has evolved through the long partnership between people and nature. We advise on policies and promote projects that aim to improve the natural heritage and support its sustainable use.

Our aim is to help people to enjoy Scotland's natural heritage responsibly, understand it more fully and use it wisely so that it can be sustained for future generations.