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Coastal Cells in Scotland:
Cell 5 – Cape Wrath to the Mull of Kintyre

D L Ramsay & A H Brampton

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REPORT

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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 5 between Cape Wrath and the Mull of Kintyre on the west coast of Scotland. 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 5 between Cape Wrath and the Mull of Kintyre 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 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 details available information of relevance to shoreline management in Cell 5. Chapter 5 forms the main body of the report. A brief description of Cell 5 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 5 is given in Chapter 6, with Chapter 7 listing the references used. A listing of Sites of Special Scientific Interest, the locations of noted historical and archaeological sites, useful addresses, and a 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, 1993). 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, 1993), resulted in its suggested division into eleven 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, such as those of western Scotland 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.

Bearing the above description of cell boundaries in mind, the coast of Scotland has been divided up into eleven 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. Cell 5 has been defined in this manner.

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 inter-relationship 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, 1995).

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 5 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 100 Ma 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. 26,000-10,000yrs) 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 Post-glacial 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.

Tidal levels

Tidal levels experienced around the Scottish coastline are generally made up of two components, an astronomical component and 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 also 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 predictions 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 always be carefully established. For the design of coastal works, it is better to use information derived from analysis of recorded 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 inter-related 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:

Sites of Special Scientific Interest (SSSI) — Scottish Natural Heritage
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 5 - 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 in Chapter 5.

Two general sources of coastal information on Cell 5 exist. The UK Digital Marine Atlas (UKDMAP) which was developed by the British Oceanographic Data Centre, Birkenhead 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, species and activities on the west coast of Scotland is provided by the *Coasts and Seas of the United Kingdom* series of reports (Barne et al, 1996 & 1997). A similar review, *The Minch Review* (Bryan, 1994), was produced by Scottish Natural Heritage and Western Isles Island Council.

Details of physical oceanographic and meteorological (metocean) data collected around the British Isles on behalf of the UK energy industry is 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 west of Scotland has been described in several publications, for example *British Regional Geology: The Grampian Highlands* (Stevenson & Gould, 1995); and *The Northern Highlands* (Johnstone & Mykura, 1989). These reports reference a large number of more detailed localised studies conducted within the region. The British Geological Survey have also produced a series of solid and drift geology maps the availability of which is detailed in Table 2. A 1:625,000 scale Quaternary geology map, covering the area is also available.

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.

Table 2 Available geological maps

Map No.	Map Name	Solid/Drift Geology	Scale
81W	Raasay	Drift	1:50,000
81E	Loch Torridon	Drift	1:50,000
71W	Broadford	Solid & Drift	1:50,000
71E	Kyle of Lochalsh	Solid & Drift	1:50,000
61	Arisaig	Solid & Drift	1:63,360
52	Tobermory	Drift	1:63,360
51W	Ardnamurchan	Solid	1:50,000
51E	Caliach Point	Solid & Drift	1:50,000
44E	Lismore	Solid	1:50,000
45W	Connel	Solid	1:50,000
36	Kilmartin	Drift	1:50,000
37W	Furnace	Solid	1:50,000
28	Jura	Solid & Drift	1:63,360
12	Campbeltown	Solid & Drift	1:50,000

Note: There are a number of geological maps for this region that are now out of print. These have not been included in the above list.

The geomorphology of the north west coastline of mainland Scotland has been studied in detail in several reports, the main ones being *The coastline of Scotland* (Steers, 1973) and *The beaches of Sutherland* (Ritchie & Mather, 1969), *The beaches of Wester Ross* (Crofts & Mather, 1972), *The beaches of West Inverness-shire and North Argyll* (Mather & Crofts, 1972), *The beaches of mainland Argyll* (Crofts & Ritchie, 1973) and *The beaches of the Highlands and Islands of Scotland*, (Mather & Ritchie, 1977). Other, more localised studies are detailed within the bibliography of this report.

4.3 Bathymetry

The bathymetry off the west coast of mainland Scotland is illustrated in detail on the Admiralty Charts detailed in Table 3.

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.

Table 3 Available Admiralty Charts

Chart No.	Location	Scale
1785	North Minch - Northern Part	1:10,0000
1790	Oban & Approaches	1:10,000
1794	North Minch - Southern Part	1:100,000
1954	Cape Wrath to Pentland Firth & Orkney Islands	1:200,000
2168	Approaches to the Sound of Jura	1:75,000
2199	North Channel - Northern Part	1:75,000
2207	Point of Ardnamurchan to Sound of Sleat	1:50,000
2208	Mallaig to Canna Harbour	1:50,000
2209	Inner Sound	1:50,000
2210	Approaches to Inner Sound	1:50,000
2320	Loch Crinan	1:7,500
2326	Loch Crinan to the Firth of Lorne	1:25,000
2343	Gulf of Corryvreckan & approaches	1:25,000
2372	Plans in Loch Linnhe	various
2378	Loch Linnhe - Southern Part	1:25,000
2379	Loch Linnhe - Central Part	1:25,000
2380	Loch Linnhe - Northern Part	1:25,000 &1:10,000
2382	Upper Loch Fyne	1:25,000
2386	Firth of Lorne - Southern Part	1:25,000
2390	Sound of Mull	1:25,000
2394	Loch Sunart	1:25,000
2397	Sound of Jura - Northern Part	1:25,000
2475	Passages on the West coast of Scotland	1:25,000
2477	West Loch Tarbert & Approaches	1:25,000
2479	Inner Sound - North Part	1:18,000
2480	Inner Sound - Central Part	1:25,000
2498	Inner Sound - Southern Part	1:25,000
2500	Loch Broom, Little Loch Broom & approaches	1:25,000
2501	Summer Isles	1:25,000
2502	Eddrachillis Bay	1:25,000
2503	Lochs Laxford & Inchard & approaches	1:25,000 &1:10,000
2504	Rubha Coigeach to Stoerhead	1:25,000 &1:12,500
2509	Rubha Reidh to Cailleach Head	1:25,000
2528	Anchorages on the west coast of Scotland	1:7,500 & 1:15,500
2540	Loch Alsh & approaches	1:20,000 &1:12,500
2541	Lochs on the west coast of Scotland	1:7,500 & 1:25,000
2720	Flannan Isles to Sule Skerry	1:200,000
2724	North Channel to the Firth of Lorne	1:75,000
2798	Loch Foyle to Sanda Island including Rathlin Head	1:75,000
3146	Loch Ewe	1:12,500

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 on the north west coastline of Scotland. At present the recorders at Cassley, Inverpolly, Aultbea and Machrihanish are equipped with Semi-Automatic Meteorological Observing Systems (SAMOS) which produce wind statistics continuously for immediate archiving. The recorder at Dunstaffnage is 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 there. At Duirinish, a graphical recorder is used, 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 5 - Availability of wind data

Location	Period covered	Anemometer Type
Aultbea	< 5 years	Analysed anemograph from SAWS/SAMOS/CDL station
Cassley	< 5years	Analysed anemograph from SAWS/SAMOS/CDL station
Duirinish	01/70 - Present	Data on Metform 6910
Dunstaffnage	07/71 - Present	Digital anemograph logging equipment (DALE)
Inverpolly	< 5 years	Analysed anemograph from SAWS/SAMOS/CDL station
Machrihanish	01/70 - Present	Analysed anemograph from SAWS/SAMOS/CDL station

4.5 Tidal data

A-class tidal gauges within Cell 5 are located at Kinlochbervie and Ullapool. A-class gauges are also situated at Tobermory, on Mull, and at Port Ellen on Islay. A-class tidal gauges are installed and maintained as part of a national network of tide-gauges organised by the Proudman Oceanographical 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. These too 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 tidal predictions derived for these sites may not be as reliable as from an A-class gauge.

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 the report *Data holdings of the PSMSL* (Spencer & Woodworth, 1993) which can be obtained from the Bidston Observatory. Within Cell 5 mean sea levels are recorded at Ullapool (and on Tobermory on Mull).

Actual tidal levels, however, can and often do, vary significantly from those predicted using harmonic analysis due to the influence of meteorological effects (surges). The UK Met Office Storm Warning Service operates 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. 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 of extremes around the coast of the UK. This research has been extended to produce a spatial analysis of extreme water levels every 20km around the UK mainland coast (Dixon & Tawn, 1997) and so includes the coastline of Cell 5. In practice, referring to these papers, or similar papers in the future, is likely to be the method used most often by coastal managers to determine extreme water levels in their area.

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 high density of current meter recording has been conducted within Loch Linnhe. Elsewhere, within this cell, the BODC directory records few current meter recording locations.

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.

Flow modelling of the Oban and Loch Linnhe area has been conducted by HR Wallingford (1996a) in conjunction with the new Oban Sewage Scheme. The modelling used a variable sized grid with a very fine resolution in a number of areas to model the complex flow patterns.

The Admiralty also produce "Tidal stream atlases" with the offshore zone of Cell 5 covered in the *North Coast of Ireland and West Coast of Scotland* atlas (Hydrographer of the Navy, 1973). 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.

4.6 Wave data

Information on offshore wave conditions can be obtained from measured 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 of the MIAS catalogue is presently being developed. Other wave recording has been conducted by commercial organisations, normally in connection with marine construction projects, e.g. harbour developments. The north-west coast of Scotland is poorly served with such data with no known locations where wave conditions have been recorded.

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 has been a large number of records spanning over many years, e.g. major shipping lanes. VOS data is 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 offshore locations 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 governmental 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 are the result of an evolving series of such models, in use since 1976. These 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, the model predictions therefore need to be transformed from 20-50km offshore to the shoreline (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 is permanently stored in an archive, whilst the data from T+0 hours to T+36 hours is 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 the west coast of Scotland. Due to the resolution of the model wave predictions are not reliable within The Minch or Sea of Hebrides. Further details are given in the table below. Modern numerical methods are also capable of accurate predictions of "wind-sea" for offshore areas, especially if there is good quality, sequential wind data available to provide the basic input conditions.

Table 5 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
Loch Inver	Offshore: Seaward of Loch Inver entrance Inshore: At location of outer breakwater	-	 -12m CD	1, 5, 10, 50 & 100 year extremes from 20° sectors	HR Wallingford
Mallaig	Offshore: Met Office wave model used Inshore: West of Mallaig	-	-20m CD	1:200 year conditions (locally generated and swell)	HR Wallingford

The final stage in numerical wave prediction is to transform such offshore wave information into corresponding nearshore conditions. This may be carried out just for 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 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 known locations where inshore wave conditions have been predicted are detailed in Table 5.

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 5 the number of designated natural heritage sites is given in the Table below:

Table 6 Natural heritage designations

Designation	Number	Designation	Number
SSSI	60	NSA	8
NNR	6	NHA	-
MNR	-	AGLV	-
LNR	-	ESA	-
SAC	8	MCA	7
SPA	1	RSPB	-
RAMSAR	1	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 locations of Sites of Special Scientific Interest are shown in Figure 7 with further information detailed in Appendix 1. Other natural heritage designations are shown in Figure 8. Advice on historical and archaeological matters is provided by a number of organisations which are detailed in Table 7.

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 location of scheduled archaeological and historical sites within 500m wide by 10km long strips along the coastline of Cell 5. Because of the low resolution these will include a large number of sites which are not truly coastal. Only where more detailed surveying has been conducted can an assessment of the number of coastal sites be determined. There are also a large number of sites of cultural heritage importance, such as Listed Buildings, which do not appear in the NMRS database.

Table 7 Cell 5 - 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.

5 Cell 5: Cape Wrath to Mull of Galloway

5.1 General

Cell 5 has been defined, (HR Wallingford, 1997), as the mainland coastline between Cape Wrath and the Mull of Kintyre. Island coastlines were, in general, excluded from this study and so are not addressed in the following sections.

The concept of coastal cells is not really applicable to this coastline due to its deeply fjorded and indented nature and the almost total lack of continuous, or semi-continuous, "soft" shoreline. Beach areas tend to be isolated bayhead or pocket beach types with little longshore sediment transport processes occurring between them. The locations of these "semi independent beach units" are shown on the various littoral process maps. This report concentrates on these beach areas where active littoral processes do occur (and hence potential coastal erosion concerns may arise), ignoring most of the rocky, neutral coastline of the sea lochs.

The Cell has been split, arbitrarily, into three sub-cells based very loosely on the exposure to offshore wave conditions. Between Cape Wrath and Rubha Reidh the most severe wave conditions will be experienced from the north and north west with significant Atlantic swell also experienced from this direction. Between Rubha Reidh and Point of Ardnamurchan, the Western Isles restrict westerly fetch lengths limiting wind generated wave conditions and also Atlantic swell. To the south of Ardnamurchan, the coastline is more exposed to the North Atlantic, although islands of the Inner Hebrides provide protection to large parts of the mainland.

5.2 Cell 5: Physical characteristics

5.2.1 General

The characteristics and processes occurring within Cell 5 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 a good summary provided by Steers (1973). 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 influence of the Ice Age, the occurrence of glacial deposits, and the influence these deposits have on the formation of beach areas and "soft" geomorphological features is extremely complex in the north west of Scotland and has been little studied. 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 in relation to their effects on the beach areas of this cell. 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 is also detailed. Any areas where significant tidal flooding is known to occur 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. Due to the nature of this coastline, the nearshore wave climate can vary considerably over very short distances, depending on the orientation, degree of shelter provided by offshore islands and rock reefs and the nature of the seabed.

The next section within each sub-cell describes the main littoral processes. Where known 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. Known 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. Much of the coastal edge of the sea lochs which occur on the west coast of Scotland is fringed with a mixture of shingle and boulders. These coastlines, at present sea levels, change little and are generally not all that dynamic under most hydraulic conditions experienced, although some movement of foreshore material and erosion can occur under storm wave conditions. Such coastlines are not described herein. Finally, locations where maintenance dredging is conducted are listed and, where possible, an indication of known dredging rates and sources of siltation.

The final section details the location, type and influences of coastal protection work. 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 presented and where possible details of the length of such records and monitoring authorities given. Details of existing coastal defences and locations where regular monitoring are conducted are shown in the relevant figures for each sub-cell.

5.3 Sub-cell 5a - Cape Wrath to Rubha Reidh

5.3.1 Geology

The bedrock of the north west of Scotland is dominated by Precambrian rocks. The oldest of these, the Lewisian Gnéiss, are among the oldest rocks in the world, parts of which having formed around 2900Ma. The gneisses are highly deformed and metamorphosed igneous and sedimentary rocks and are extremely resilient to marine erosion. In the north west of Scotland, this rock appears as high vertical cliffs around Cape Wrath, but elsewhere is hummocky, often forming small islands offshore. The Torridonian Sandstones, which are the other dominant bedrock type occurring within the region are younger. These are sedimentary rocks which have undergone little metamorphism. This rock can either form high vertical cliffs or can slope gently to the shoreline and forms a completely contrasting coastline to the Lewisian Gneisses. The Torridonian Sandstones are softer than the older Gneisses and erosion of this rock during periods of glaciation has provided a source of beach material.

To the south of Loch Laxford there are numerous north west to south east dykes which outcrop at the coast. It is these small scale localised features which, due to differential erosion rates, have produced the rugged coastline of the north west coast. The lack of a source of beach material and the nature of the coastline has resulted in few beach areas.

Little glacial sediment is present within this sub-cell, mainly limited to localised boulder clay which caps the bedrock. The general movement of the ice sheets across this region was to the north west. However, offshore the seabed gradients are steep and only localised glacial deposits exist. This is reflected in the lack of beach areas, but where beaches do exist many of these have a high proportion of sediment derived from localised offshore sources (both glacial and derived from shell sources). During late- and postglacial times, varying sea levels have formed a range of coastal geomorphological features around the Scottish coast. However, there is little evidence of this in the northern part of this sub-cell, primarily due to the lack of beach sediments to form such features. Further south, particularly on the coastline around Loch Broom, there is much more evidence of sea level change, such as raised deltas and beach areas, for example the one which Ullapool stands upon.

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 4.2m at Kinlochbervie to about 4.6m in Loch Ewe, but there are small variations depending on the location, particularly in Badcall Bay where the spring range is 3.6m. The corresponding mean neap range varies between 1.6m and 1.9m. A-class tidal recording gauges are located at Kinlochbervie and Ullapool. The flood tide takes approximately 1.5 hours to travel northwards along this sub-cell.

Table 8 Tidal levels and ranges for Cell 5a

Location	MHWS (m OD)	MLWS (m OD)	Spring Range (m)	MHWN (m OD)	MLWN (m OD)	Neap Range (m)	ODN to CD (m)
Loch Bervie	2.40	-1.80	4.2	1.10	-0.60	1.7	+2.50
Loch Laxford	2.40	-1.80	4.2	1.00	-0.90	1.9	+2.50
Ullapool	2.45	-2.05	4.5	1.15	-0.75	1.9	+2.75
Mellon Charles	2.33	-2.07	4.4	1.03	-0.97	2.0	+2.77

In Table 8 the tidal elevations are quoted relative to Ordnance Datum Newlyn (the standard land based datum). The conversion to the local Chart Datum (where known) is shown in the final column.

The most commonly referred to research on extreme water levels in the UK is that conducted by Graff (1981) and Coles & Tawn (1990). This analysis was based on tidal records from the A-class tide gauge network. In these publications the only locations in sub-cell 5a where predictions of extreme water levels have been made is Ullapool, Table 9.

Table 9 Extreme water level predictions at Ullapool

Graff (1981):

Location	Return period levels (height above ODN (m))						
	1	5	10	20	50	100	250
Ullapool	3.16	3.41	3.46	3.53	3.61	3.63	3.68

Coles & Tawn (1990):

Location	Probability of annual maximum tidal levels (m ODN)		
	10%	1%	0.1%
Ullapool	3.79(± 0.29)	4.04(± 0.46)	4.24(± 0.74)

The latest research into trends of extreme water levels (Dixon & Tawn, 1997) provides a spatial analysis at any location around the coastline of the UK mainland. In this study the predicted extreme water levels depend on the year of interest allowing for trends in mean sea level rise and hence have not been reproduced in this report. This research is likely to provide the most up-to-date and comprehensive analysis of extreme water levels available. There is little other information. The 1:50 year return period surge (BODC, 1991) is calculated to be between 1.25m and 1.5m. However, it should be noted that tidal elevations and extreme water levels may vary considerably along this coastline as levels may well be amplified within the sea lochs.

The main flood stream flows in a north-easterly direction through The Minch with the ebb returning in the opposite direction. Offshore of Cape Wrath the peak mean Spring current speed is approximately $0.85ms^{-1}$ on both the flood and the ebb. The ebb flow is likely to form an eddy closer to the shoreline between Eilean an Roin Mor and Cape Wrath resulting in a continuous northward stream along this coast.

The strengths of the tidal streams are highly variable, being strongest off the headlands and in the channels between the offshore islands, such as in the Sound of Handa. Peak speeds are of the order of 1 to $1.5ms^{-1}$. Eddies formed due to these strong currents are a common feature, but are unlikely to have any significant influence on the few beach areas. Within the sea lochs and bays streams are generally negligible, e.g. Eddrachillis and Enard Bays. At the entrance to Loch Broom and Little Loch Broom peak rates reach about $0.5ms^{-1}$ with similar rates in the narrow parts of the channel around Isle of Ewe. Elsewhere close to the shoreline rates are inappreciable.

The offshore total wave climate within the eastern Minch will be dominated by both waves generated further afield in the Northern Atlantic and more locally generated wind-waves from within the Minch. The coastline is exposed to large fetch lengths to the north through to north west. An analysis of wave conditions offshore of Cell 5 (HR Wallingford, 1998) indicated that the significant wave height with a return period of 1 year at the northern end of The Minch can be 10m in height with a corresponding swell wave height of 6m. Swell waves generated from further west in the North Atlantic will still have a considerable influence upon this coastline, being diffracted into The Minch around the Butt of Lewis.

The extreme wind conditions experienced on the west coast of Scotland can result in almost as large wind wave conditions being generated locally from within the Minch. Extreme wave heights at Lochinver were calculated by HR Wallingford (1989) during a study into the development of the harbour. Offshore of Loch Inver the maximum extreme wave heights occur from the north with significant wave heights of about 7.8m for the 1:50 year return period. Where fetch lengths are restricted, i.e. between about 215°N and 315°N the maximum significant wave heights for the 1, 50 and 100 year return periods were calculated to be 3.3m, 4.8m and 5.0m respectively.

Wave conditions inshore are spatially extremely variable due to the orientation, indented characteristics of the coastline, degree of shelter provided by offshore islands and rock reefs and the character of the nearshore seabed. For example under a 1:50 year return period, there is little wave activity within Loch Inver outwith the directional sector between 265°N and 325°N. The directional sector is even more restricted in the longer sea lochs, such as Loch Broom.

5.3.3 Littoral processes

Beaches within sub-cell 5a are few, mainly restricted to sheltered bays (Figure 12). The largest beach systems are generally sandy with the beach material forming them derived from a variety of sources. The dominant sources are likely to have been the reworking of glacial deposits. However, on most of the sand beach systems the shell content of the sand is extremely high indicating that organic sources have also been important. Coarser sands are apparent on a number of beach systems, such as at Clachtoll and Mungersdale. These are likely to have been derived from erosion of Torridonian Sandstones during former periods of changing sea level.

All the sand beach systems within this sub-cell are extremely stable in terms of marine processes, Figure 13. The beaches have developed into equilibrium bay shapes which are dependent upon the incident wave directions (particularly of swell waves), i.e. there is little evidence of longshore processes. There is also little evidence, except at Oldshoremore, of present day frontal dune erosion due to wave action at any of the beach units. However, episodic storm damage of the frontal dune systems will occur with the extent of damage largely dependent upon the wave direction. Cross-shore transport processes are evident on some of the more exposed beaches with storm conditions tending to draw sand into the nearshore zone which is then moved onshore by constructive swell action, such as on the beach system at the southern end of Gruinard Bay. At Laide, on the western side of Gruinard Bay, there is slight undercutting of the coastal edge in front of the caravan park.

Wind action is a much more destructive process upon the sand beach systems in this region. The problems with dune erosion and deflation of machair surfaces due to wind action (but often initiated or exacerbated by heavy recreational use) is well documented, e.g. in the Beaches of Scotland reports (Ritchie & Mather, 1969; Crofts & Mather, 1972; Mather & Ritchie, 1977) and the Highland Beach Management Project (CCS, 1979). Many of the machair sites are still in an extremely fragile state, as at Achmelvich and Achnahaird, but the apparent reduction in the density of tourist use and caravanning upon these sites has helped reduce the damage since these studies were conducted.

Much of the coastal edge is fringed by thin gravel and cobble beaches which are relatively stable with little dynamic response evident. There are a number of interesting shingle features, such as the salient at Ardmair and at Inverasdale where larger accumulations of shingle display evidence of the action sea levels played in developing such features. The only other area of note is the foreland at Ullapool. There is still a very low drift of material towards the promontory on both sides of the foreland. Fluvial material deposited by the river to the north of Ullapool is transported in a southward direction, towards the point, by wave action propagating into the loch. On the southern side, build up against a slipway at the eastern end of the village suggests a low north westerly movement due to locally generated wave conditions within Loch Broom.

Maintenance dredging has been conducted at Ullapool in 1988 by the Ullapool Port Authority. Capital dredging, to increase water depths, has also been conducted at Lochinver and Kinlochbervie. None of this dredging will have had an adverse affect on any beach units nor will the dumped dredge material provide a source of beach sediments as there are no beach units close to either the dredged or dump sites.

<u>Summary of erosion and accretion</u>

There are no areas of significant net erosion or accretion within this sub-cell. Periodic storm damage of the frontal dune systems will occur but the effect on any particular beach unit will be dependent upon the storm direction. However, wind action continues to have an erosive influence upon the fragile dune and machair systems backing most of the sand beaches.

5.3.4 Coastal defences

There is little coastal defence work within this sub-cell due to the lack of developed areas and infrastructure, Figure 14. Most defences are associated with the main harbour areas at Kinlochbervie, Lochinver and Ullapool. At Lochinver the village frontage follows the coastline along the edge of the head of the loch. Virtually the entire frontage is protected by a rock revetment, apart from a few short sections of masonry seawall. These structures are in good condition, with little evidence of wave damage, and appear to be performing adequately. Just to the south of Lochinver, at the head of Loch Kinkaig, a low vertical seawall and sections of rock breakwater provide protection to the road as it skirts the coastal edge at the head of the Loch.

At Ullapool a rock revetment protects the tip of the promontory where the sewage outfall crosses the shoreline. Additionally much of the southern town frontage to the east of the pier is protected by a sloping blockwork revetment. Both these defences are in a structurally sound state with minimal impact on the surrounding coastline evident. A slipway at the eastern end of the revetment does act as a groyne to a very low northwesterly longshore drift of material, but there is no evidence of downdrift effects along the town frontage. Elsewhere a number of short sections of masonry wall protect the road to the west of Aultbea, with some tipped rock rip-rap placed at the coastal edge in front of the church at Aultbea.

5.4 Sub-cell 5b - Rubha Reidh to Point of Ardnamurchan

5.4.1 Geology

The Lewisian Gneisses and Torridonian Sandstones which dominate the coastline at the extreme north west of Scotland continue in the northern part of this sub-cell until around Loch Hourn. Along this coastline it is dominantly the Torridonian Sandstones which occur at the coastline, although outcrops of Lewisian Gneisses occur around Loch Gairloch and Loch Torridon. The sub-cell is split by the Moine Trust which appears on the west coast around Loch Carron. The Moine Thrust is a major fault which involved the thrusting of the Moine Schists, which occur to the east of the thrust zone, over the older gneisses and Torridonian Sandstones to the west.

The Torridonian Sandstone does not outcrop at the coast further south than Loch Alsh, with the northern coastline of Loch Hourn being the southern limit of Lewisian Gneiss. The Moinian rocks which occur to the east of the Moine Thrust zone are generally mica-schists and siliceous schists which have resulted from the metamorphism of sandstone and shales of Precambrian age. This rock type forms a heavily indented coastline with numerous offshore rock reefs and islands and has had a dominating influence on the planshapes of the beach areas occurring within this region. The peninsula of Ardnamurchan is of igneous origin with a complex series of dykes and cone sheets outcropping obliquely to or running parallel with the coast.

A wide range of glacial and postglacial features, such as raised beaches and machair, are evident along this coastline. Most of these are small scale and localised, with no long stretches of coastline backed by raised beach and fossil cliffs, as occurs for example along much of the western freeboard of the Kintyre peninsula in the sub-cell to the south. For example near Arisaig a late glacial beach consisting of an accumulation of gravel on a platform cut in drift reaches a height of almost 1.5m.

5.4.2 Hydraulic processes

The mean spring and neap tidal ranges are shown in Figure 11 and in Table 10. The mean spring tidal range is macro tidal varying from 4.2m to 4.9m with the mean neap range showing a similar variation (1.5m to 2.3m) depending upon location. There are no A-class tidal gauges within this sub-cell. High tide takes approximately 1 hour to travel the length of this sub-cell.

Table 10 Tidal levels and ranges for Sub-cell 5b

Location	MHWS (m OD)	MLWS (m OD)	Spring Range (m)	MHWN (m OD)	MLWN (m OD)	Neap Range (m)	ODN to CD (m)
Gairloch	2.50	-2.10	4.6	1.30	-0.90	2.2	+2.70
Shieldaig	2.76	-2.14	4.9	1.36	-0.64	2.0	+2.84
Applecross	2.40	-2.20	4.6	1.10	-0.70	1.8	+2.90
Plockton	2.55	-2.25	4.8	1.25	-0.55	1.8	+3.15
Kyle of Lochalsh	2.57	-1.93	4.5	1.17	-0.53	1.7	+2.73
Dornie Bridge	2.62	-1.98	4.6	1.12	-0.58	1.7	+2.68
Glenelg Bay	2.15	-2.05	4.2	0.85	-1.45	2.3	+2.65
Loch Hourn	2.35	-1.85	4.2	1.15	-0.65	1.8	+2.65
Mallaig	2.38	-1.82	4.2	0.98	-0.52	1.5	+2.62

In Table 10 the tidal elevations are quoted relative to Ordnance Datum Newlyn (the standard land based datum). The conversion to the local Chart Datum (where known) is shown in the final column.

The most commonly referred to research on extreme water levels in the UK is that conducted by Graff (1981) and Coles & Tawn (1990). This analysis was based on tidal records from the A-class tide gauge network, hence there are no locations within sub-cell 5b where extreme water levels have been predicted.

The latest research into trends of extreme water levels (Dixon & Tawn, 1997) provides a spatial analysis at any location around the coastline of the UK mainland. In this study the predicted extreme water levels depend on the year of interest allowing for trends in mean sea level rise and hence have not been reproduced in this report. This research is likely to provide the most up-to-date and comprehensive analysis of extreme water levels available. There is little other information. It should also be noted that tidal elevations and extreme water levels may vary considerably along this coastline as levels may well be amplified within the sea lochs.

The main flood stream flows in a northerly direction through the Little Minch and Minch well offshore of the mainland coastline. The main flood stream closer to the shoreline flows in a north easterly direction and splits around Ardnamurchan Point with part of the flow travelling along the southern coastline of the Ardnamurchan peninsula. For about three hours before high water at Ullapool flows travel northwards through the Sound of Sleat and meet a southerly going stream in Inner Sound, which can cause variability in the streams around Kyle of Lochalsh. A southerly going stream exists in both Inner Sound and the Sound of Sleat for 4 hours after high water at Ullapool.

The strengths and direction of the tidal currents can be highly variable in the many channels between the numerous islands and sea lochs and also off the salient points. For instance in the channel between Kyle of Lochalsh and Kyleakin the currents are extremely variable depending upon the tidal range. Eddies formed due to strong currents are a common feature. Tidal currents are generally very low close inshore and in the many bays and are insignificant in terms of littoral processes upon the main beach areas within this sub-cell.

There is little information upon wave conditions along this coastline. The offshore wave climate to the north of Skye will be very different to that experienced to the south. North of Skye, the coastline is exposed to large fetch lengths to the north from which the most severe wave conditions will be experienced. The west coast of Scotland is exposed to considerable swell wave energy both from the North Atlantic and from the Arctic Ocean. Swell will propagate into the Minch both directly from the north and from the west by diffracting around the Butt of Lewis.

To the west of Ardnamurchan Point, wave conditions have been predicted using the Met Office European Wave Model. The offshore total and swell wave climate typical of the region to the south west of Rum is shown in Figures 15 and 16 respectively. The dominant wave conditions are experienced from the west, although this reduces to the north due to the shelter provided by the Western Isles. Extreme wave conditions can be experienced from almost any westerly directional sector due to the long fetch lengths and extreme wind conditions. The total sea extreme wave conditions predicted by this model are given in the table below:

Table 11 Total sea extreme significant wave heights

Return Period (Years)	Significant wave height (m)
1	12.41
10	14.82
100	17.09

Swell waves, Figure 16, can contribute a large proportion of the total wave energy experienced in this region. The largest percentage of swell is generated in the Atlantic and propagates into the region around the southern tip of the Western Isles resulting in a narrow wave window for the most frequent conditions. Extreme swell conditions for this offshore region are detailed in Table 12.

Table 12 Swell extreme significant wave heights

Return Period (Years)	Significant wave height (m)
1	6.45
10	8.15
100	9.82

The nearshore wave conditions are extremely variable (even over very short distances), due to the changes in orientation and indented character of the coastline, the degree of shelter provided by offshore islands and rock reefs and the character of the seabed. Despite the severity of the wave conditions propagating into the Sea of Hebrides, locally generated wave conditions may be more significant in many areas. Detailed numerical modelling at Mallaig was undertaken during further development work at Mallaig Harbour (HR Wallingford 1996b). The 1:200 year swell wave height within the Sea of Hebrides was predicted to be about 14.6m from about 270°N. Just offshore of Mallaig in a water depth of about 25m this wave condition was reduced to about 1.2m, due to nearshore dissipation processes and shelter provided by the offshore islands. However locally generated wind-wave conditions were predicted to be approximately 2.4m for the same return period from the same direction. Elsewhere there is little information on nearshore wave conditions.

5.4.3 Littoral processes

There are few beach units occurring within this sub-cell other than dynamically stable shingle and cobble fringe beaches which are found around many of the sea lochs on the west coast of Scotland, Figure 17. There are a number of beaches around Gairloch but the main beach units within this sub-cell occur around Morar, Arisaig and the northern coast of the Ardnamurchan peninsula.

The Gairloch complex of beaches are all pocket beach types. The beaches are dominantly sandy although a number have a shingle upper beach, such as at Big Sands, and nearly all are backed by extensive dune and machair systems. Beach sediments will have derived almost entirely from reworked glacial deposits and from shell fragments. There is little fresh supply of sediments with all the systems being extremely stable under the commonly occurring marine processes, i.e. there is minimal longshore transport evident and beach planshapes are extremely stable, Figure 18. The exposure of a number of these beaches, e.g. the south beach at Gairloch, can result in storm activity moving material into the nearshore zone. However, there is generally an abundance of material below low water off most of the sandy beaches and swell wave action will move this material back onshore. During the summer of 1996, all the beaches in the area appeared to have a healthy volume of beach material with very little indication of frontal dune erosion. The dune machair systems also appeared to be in an extremely healthy state with little evidence of serious wind erosion or surface deflation.

Between the estuary of the River Morar and Arisaig the coastline is characterised by small sandy beach units interrupted by rock outcrops, reefs and skerries which provide some degree of shelter to the beach units from severe wave action. Despite the occurrence of sandy bays along this entire frontage there is a distinct difference between the beaches. The sand material found within, and on the beaches around the River Moray estuary, and the beach unit at Camusdarach has derived from the onshore movement of offshore glacial deposits. The beaches to the south of Camusdarach have a much greater shell content with this having been the dominant source of beach material. The low supply of shell material has resulted in a lack of any dune system and a relatively thin machair complex. The beaches along this coast are all in a relatively stable state in relation to the marine processes acting upon them. The most exposed frontage is at Camusdarach where few offshore rock reefs exist to provide shelter to the beach with storm wave damage of the frontal dunes evident. Elsewhere along the Arisaig beaches much protection is provided by the intertidal rock reefs and islands. Storm damage of the frontal machair edge will occur but is probably not as serious as that caused by the high density of camping and caravanning upon the machair.

Along the northern coast of the Ardnamurchan peninsula a number of small pocket beaches occur, backed by dunes and machair. Most are in a generally stable condition in relation to the incident marine processes. The largest beach unit, Sanna Bay, shows signs of some frontal dune wave damage.

There are no known locations within this sub-cell where maintenance dredging is conducted.

Summary of erosion and accretion
There are no locations where significant erosion or accretion is occurring. Episodic storm damage on the frontal dune systems is most evident on the beaches around Gairloch, Camusdarach and Sanna Bay.

5.4.4 Coastal defences

Little coastal defence work has been conducted within his sub-cell and is limited to protecting coastal village frontages or short stretches of road, Figure 19. At Gairloch much of the coastal edge of the northern bay is protected by a low concrete seawall with recurve. This appears to be in a reasonable condition, with little present day impact on the immediate beach. To the south of Gairloch, short stretches of rock revetment protect the A832 and the village frontage at Charlestown.

Masonry seawalls occur along many of the small villages, such as at Plockton and Kyle of Lochalsh. All are relatively old and periodic maintenance is required. Stretches of rock revetment protect the A896 at Kishorn and sloping gabions and a rock revetment have been built at Lochcarron. Beach material fronting most of these defences is generally thin and relatively immobile, due to the sheltered nature of many of the sites and the type of beach material (shingle/cobbles), with little detrimental impact caused by these defences on the immediate coastal zone.

The only other major defences occur around Mallaig where the town frontage is protected by rock revetments. These all appear to be in a reasonable condition.

5.5 Sub-cell 5c - Point of Ardnamurchan to Mull of Kintyre

5.5.1 Geology

Igneous and metamorphic rock dominate the solid geology of this sub-cell. In Morvern, Tertiary intrusive igneous rocks dominate the coast. To the south of Loch Linnhe, Lower Old Red Sandstone Lavas (mainly basalt and andesite) occur. The remainder of the sub-cell is dominated by Dalradian metamorphic rocks, mainly schists, quartzite and slates. On a more localised scale, faulting, fractures and fissures have resulted in differential erosion rates forming the indented character of the coastline.

Much of the solid geology results in a hard coastline with little beach sediment, particularly in the northern part. Where there is a greater abundance of sediment, such as along parts of the Kintyre peninsula, outcrops of the solid bedrock can have considerable influence in firstly providing sheltered regions for beaches to form and secondly, controlling the planshape response of these beach areas.

Glaciation, as on all parts of the west coast of Scotland, had an important part in the formation of present day coastal features. Much of the sediment which has formed the beach units within this sub-cell has derived from glacial deposits. Previously higher sea levels, and the effects of isostatic uplift, have resulted in a large number of well developed raised beaches and fossil cliffs within sub-cell 5c. The coastline surrounding the Firth of Lorn and Loch Linnhe (and the island of Lismore) displays some of the most well defined late and post glacial raised beaches in Scotland.

5.5.2 *Hydraulic processes*

The mean spring and neap tidal ranges for this sub-cell are shown in Figure 10 and detailed in the table below. The mean spring tidal range varies from about 4m in Loch Sunart to less than 1m on the western coastline of the Kintyre Peninsula. Similarly the neap tidal range varies from about 1.7m in Loch Sunart to around 0.5m in the south of the sub-cell. The reason for the variation is the occurrence of an amphidromic point in the vicinity of Islay (i.e. a location where the tidal range is zero).

In Table 13 the tidal elevations are quoted relative to Ordnance Datum Newlyn (the standard land based datum). The conversion to the local Chart Datum (where known) is shown in the final column.

The most commonly referred to research on extreme water levels in the UK is that conducted by Graff (1981) and Coles & Tawn (1990). This analysis was based on tidal records from the A-class tide gauge network, hence there are no locations within sub-cell 5c where extreme water levels have been predicted.

Table 13 Tidal levels and ranges for Cell 5c

Location	MHWS (m OD)	MLWS (m OD)	Spring Range (m)	MHWN (m OD)	MLWN (m OD)	Neap Range (m)	ODN to CD (m)
Loch Sunart	2.40	-1.60	4.0	1.20	-0.50	1.7	+2.2
Corran	2.44	-1.26	3.7	1.34	-0.26	1.6	+1.96
Corpach	2.02	-1.48	3.5	0.92	-0.38	1.3	+1.98
Port Appin	2.25	-1.15	3.4	1.15	-0.05	1.2	+1.95
Dunstaffnage Bay	2.00	-1.30	3.3	0.90	-0.20	1.1	+2.1
Oban	1.90	-1.40	3.3	0.80	-0.30	1.1	+2.1
Siel Sound	1.76	-0.54	2.3	1.06	0.16	0.9	+0.94
Loch Melfort	1.2	-1.0	2.2	0.5	-0.3	0.8	+1.60
Loch Beag	1.53	-0.57	2.1	0.83	0.13	0.96	+0.87
Carsaog Bau	1.29	-0.31	1.6	0.69	0.19	0.88	+0.61
Sound of Gigha	0.9	0.0	0.9	0.7	0.2	0.9	+0.6
Machrihanish	Mean range 0.5m						+0.66

Estimates of extreme water levels have also been made by Dixon & Tawn (1994) who have provided predictions based on tidal elevation data from the tidal gauge at Tobermory on Mull. This research has been superseded by (Dixon & Tawn, 1997) which provides a spatial analysis of extreme water elevations at any location around the coastline of the UK mainland. In this study the predicted extreme water levels depend on the year of interest allowing for trends in mean sea level rise and hence have not been reproduced in this report. This research is likely to provide the most up-to-date and comprehensive analysis of extreme water levels available. There is little other information. It should also be noted that tidal elevations and extreme water levels may vary considerably along this coastline as levels may well be amplified within the sea lochs.

The main flood stream flows up through North Sound and around the western coastline of the Island of Islay. Along the western mainland coastline, the flood flows to the north along the coastline of the Kintyre peninsula and through the Sound of Jura and into the Firth of Lorn. The main stream passes the western end of Lismore and splits, with part of the stream flowing north westward through the Sound of Mull and part flowing into Loch Linnhe. The ebb acts in the reverse direction with strong currents experienced at the Corran Narrows, between Lismore and Mull and in the Sound of Luing.

The Met Office European Wave Model has been used to predict the offshore wave climate to the west of Islay and is shown in Figures 20 and 21 for the total sea and swell sea respectively. More than half of wave conditions experienced in this offshore region occur from a narrow wave window to the west, although waves over 8m in height can be experienced from virtually the whole of the westerly sector. Extreme total sea wave heights are shown in Table 14.

Table 14 Total sea extreme significant wave heights

Return Period (Years)	Significant wave height (m)
1	11.80
10	14.12
100	16.29

Dominant swell wave conditions are similarly experienced from a very narrow wave window to the west, with Atlantic swell being a significant component of the total offshore wave energy. Extreme offshore swell wave conditions, predicted by the Met Office European Wave Model are shown in Figure 21.

Table 15 Swell extreme significant wave heights

Return Period (Years)	Significant wave height (m)
1	5.07
10	6.09
100	7.04

Along the western coastline of mainland Scotland the severe wave conditions which can be generated in the North Atlantic will not have too great an influence upon the mainland coastline due to the protection provided by Mull, Islay, Jura and the countless smaller islands. Only in the Firth of Lorn, and along the southern half of the Kintyre peninsula will offshore Atlantic waves propagate close to the shoreline. Locally generated wind waves will have a much greater influence upon most of this coastline. The magnitude of wave conditions experienced at the coast will be extremely variable depending upon wind direction, with fetch lengths varying considerably with minor changes in direction, the orientation of the coastline, the degree of shelter of offshore islands and rock reefs and the character of the immediate seabed. Such locally generated wave conditions tend to have much shorter periods which tends to result in a seaward movement of beach sediment. This can be seen in that the most well nourished beach systems along this coastline are, in general, located where swell wave action is also experienced, such as along the western coastline of the Kintyre Peninsula.

5.5.3 Littoral processes

Sandy beaches account for a very small fraction of the coastline within Sub-cell 5c, Figure 22. There are a small number of shingle pocket beach units which occur around the around the outer coastline of Loch Linnhe and to the north of Oban, but it is along the western coastline of the Kintyre Peninsula that the majority of the beach systems in this sub-cell are found.

Along the northern coastline of Loch Linnhe, between Kingairloch and Sallachan, four small pocket beach systems have formed backed by raised beaches. Shingle and small cobbles are the dominant beach material. The beaches will have been much more dynamic during periods of higher sea levels, but at present are stable with little hydraulic processes evident, Figure 23.

To the north of Oban there are a number of larger bayhead beach types, e.g. Cuil, Airds Bay, Tralee and Ganavan. Beaches are dominantly of fine shingle, although sand occurs on the lower intertidal beach at Tralee and is the dominant material at Ganavan. All the beach complexes are extremely stable in relation to the dominant hydraulic processes forming static equilibrium beach planshapes. The occurrence and stable planshape of these beaches are governed by North Atlantic swell waves which propagate up the Firth of Lorn and the narrow wave window which affects most of these beach systems. At Ledaig Point the spit has developed due to the strong tidal currents which occur through the narrows at the mouth of Loch Etive. Very little storm erosion is evident at any of these beaches with the shingle banks above the high water mark covered in vegetation. However, overwashing of the shingle beach at Tralee has been noted (Crofts & Ritchie, 1973, Williamson & Partners, 1983). Backing the main beach at Ganavan is a low concrete seawall. At present waves do not interact with the wall with there being a wide sandy beach above the high water mark.

Between Oban and the southern end of Knapdale few beaches exist, apart from a small number of dominantly shingle bayhead and pocket beach units. All of these systems are dynamically stable in relation to the incident hydraulic processes, with little loss or gain of beach sediments. Storm damage will occur, but the magnitude of damage is variable depending on the storm direction. Along the southern coast of Loch Caolisport there are a number of small sandy beaches. Of particular note is the tombolo which links Eilean Traighe to the mainland at Ormsary. This feature will have formed under formerly higher relative sea levels. There is evidence of overwashing of the crest of the tombolo and a rock revetment has been constructed on the western flank. Elsewhere within Loch Caolisport there is little evidence of marine erosion.

To the south of West Loch Tarbert, along the western Kintyre peninsula, the coastline changes considerably with more beaches. The occurrence of beach material can be linked to the increased exposure to Atlantic swell experienced along this coastline, which, when sea levels were rising following the Ice Age resulted in offshore sand and gravel deposits being transported landward. At the northern end Dunskeig Bay and Ronachan Bay are small sandy bays, both of which are in an extremely stable situation with no evidence of erosion.

The beach complex of Rhunahaorine is one of the largest found along this coastline. The formation of Rhunahaorine Point will have occurred during postglacial times due to the action of swell waves diffracting around the island of Gigha, creating zones of northward and southward drift on the mainland coast in its lee, and thereby producing a salient. There appears to be little present day material in the offshore zone for the continual development of this feature which is now relatively stable, with little longshore drift along the flanks of the salient evident. At present, locally generated wave conditions will have a much greater influence on this coastline. Along the northern flank there is presently a healthy well vegetated shingle ridge. However, evidence of frontal erosion of the sand and shingle deposits backing the beach indicates that the shingle beach profile can be extremely dynamic under a north westerly storm.

Slight erosion of the low coastal edge (is evident) around the Rhunahaorine Point. Along the Tayinloan coastline, as far south as Glenacardoch Point, the beach material is dominantly sand, intersected by rock outcrops and backed by a wide raised beach area and fossil cliffs. The rock reefs provide hinge points upon which a number of bays have formed. There is little evidence of longshore transport processes with all of this coastline in an extremely stable state, vegetation covering the upper beach and some embryo dune formation.

Between Glenacardoch Point and West Port, the coastline is characterised by thin sandy beaches resting upon, and dissected by, rock reefs and outcrops. This coastline is directly exposed to waves from the North Atlantic propagating between Mull and the Irish coast. As a result there is marginally more evidence of backshore erosion along sections of this shoreline, e.g. at Glenbar. However, the rate of erosion is not severe.

At the southern end of this sub-cell, the beach-dune-machair system at Machrihanish is the longest sand beach within Cell 5. The intertidal beach is wide and shallow sloping with beach sediments, and those of the hinterland, having been supplied almost exclusively from offshore glacial deposits moved onshore by swell wave action. At present there is little evidence of any nett longshore transport processes. The dune face along much of the frontage is at present in a relatively healthy state with sand accreting upon the face. At the northern end, where the width of the beach above high tide is narrower, storm wave action will affect the front dunes. However, frequent swell conditions will quickly restore beach sediments onto the upper beach.

There are no known locations where dredging of marine sediments is routinely conducted within this sub-cell.

<u>Summary of erosion and accretion</u>
The only location where any significant ongoing erosion appears to be occurring is along the coastline to the north of Rhunahaorine Point. Other than this there is little evidence of beach and coastal edge erosion other than episodic storm damage which tends to be more evident on the exposed beach units, such as Machrihanish. There is little evidence of any beach accretion within this sub-cell.

5.5.4 Coastal defences

As with much of the western coast of Scotland, there are few constructed defences within this sub-cell, Figure 24. At Ganavan a low concrete seawall protects the coastal edge with minimal impact at present. High vertical seawalls also front most of the Oban town frontage, but given the lack of beach material, there will be no impact on littoral processes. Elsewhere only minor areas of the coast have been protected, e.g. at Crinan where an old low masonry wall occurs. Along the Kintyre peninsula a short length of rock revetment protects the A83 at Port Corbert.

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

5.6.1 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 post glacial 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.

5.6.2 Natural heritage sites

Figure 7 shows the location of coastal SSSIs within Cell 5, with a summary of their main characteristics provided in Appendix 1. There are 60 coastal SSSI within Cell 5 many of which have been designated on account of geological or geomorphological features. The solid geology within Cell 5 is generally resilient to marine processes with the rate of attrition low. Present day influences of coastal processes are unlikely to have any noticeable affect upon these designations.

There are few designated sites on "soft" sandy coastlines, the only ones of note being the Machrihanish complex, Oldshoremore and at Sandwood Bay. In general these systems are all in a relatively dynamically stable state in terms of the incident hydraulic processes. At Machrihanish a number of old blowout features are still active, but erosion due to wind action of the frontal dunes appears to be much less than noted during the early 1970s when the *Beaches of Mainland Argyll* report was produced (Crofts & Ritchie, & Crofts, 1973). The reduction in recreational use of the beach, and trampling of the dunes, may be an important factor in the present day stability of these features. At Sandwood, the dune system is highly dissected due to the exposed location (which will not change). This dune evolution process has been entirely natural (in response to the natural forcing processes i.e. wind) and is likely to continue due to the lack of human influence at this location. At Oldshoremore the evolution of the beach system will continue in a natural manner. The beach system is relatively stable although some storm damage of the frontal dunes does occur. Erosion of the machair is evident with seriously deflated areas but is no worse than many other sites on the west coast of Scotland. Provided sheep grazing and the rabbit population are controlled the machair will continue to evolve naturally.

5.6.3 Cultural heritage sites

The location of archaeological sites from the NMRS database is shown in Figure 8 and Appendix 2. Little survey work appears to have been conducted along the coastline of Cell 5 to establish the present threat of coastal erosion to sites of cultural heritage (Ashmore, 1994).

There are a large number of sites noted in the NMRS database which occur within 500m of the coastline within Cell 5. In general terms a very small proportion of the cell can be termed "soft" where erosion events could occur. Similarly many of the sea lochs are fringed by stable shingle and cobble fringe shorelines where limited sediment movement occurs. Hence, the nature of much of the coastline results in there being little overall risk to sites of cultural heritage due to present day coastal processes. However, there is still a localised threat to sites of cultural heritage where a "soft" coastline occurs. Many of the "soft" beach areas within this cell are hydraulically stable with the planshape of these systems having developed in response to the incident hydraulic conditions and the outcrops of the solid geology. At present there will be little change in the general shape of these beach areas, without a substantial change in the hydraulic climate. However, short term storm damage can still occur. There was little evidence of storm damage on most of the beach systems during the period of this report but this may be due to the increased occurrence of storm conditions from the east which have been experienced over the last few years which do not have such an influence upon this coastline. In summary, sites which have not been affected by storm damage in the past are unlikely to experience any great increase in the risk of damage due to marine influences.

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 levels 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 70-100 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 longshore 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 the beaches in Cell 5

The majority of the beach areas within this cell are in an extremely stable state in relation to the present day hydraulic climate. In Cell 5 most of the beach areas are in the form of pocket or bayhead beaches. The planshape on such beaches does not change dramatically, even if the offshore wave direction changes, as wave conditions at the shoreline are dominated by wave diffraction around the headlands at either end of the bay. Similarly because many of these pocket beaches have adjusted and reached a position of no nett drift, a change in wave heights will have no effect on the longshore transport. 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. Hence it is unlikely that mean sea level rise will have a significantly noticeable effect. The greatest impact on these pocket beach areas is likely to be due to any increase in extreme tidal levels. This will cause an increase in dune or backshore erosion, particularly in the beach areas where there is little present day width between the high water mark and the frontal dunes/coastal edge or where streams run onto the middle of the beach causing beach levels to be lower.

Greater impacts will be experienced upon the longer beach systems where the effects of the solid geology are reduced, such as at Machrihanish. The response of such coastlines to climatic change and sea level rise is dependent on the balance of the sediment budget, i.e. between sediment supply and sediment loss, (Carter, 1988). Along the frontage at Machrihanish, coastal edge retreat will take the form of an erosional response. This erosion, induced by an increase in sea level, is a result of changes in wave refraction and a decrease in distance to the zone of breaking, due to deeper water. Waves and currents also tend to act higher up the beach profile. However, the exposed sections of this coastline are also influenced by significant swell energy which tends to "repair" beaches drawn down by storm damage and move sediment onto the beaches.

Elsewhere, such as the beach system at Tralee, overwashing of the shingle ridge is likely to increase. This will cause rollover with beach material progressively transferred from the shore face, pushed over the crest and onto the back face hence causing a landward retreat. The average rate of retreat is approximately proportional to sea level rise and the gradient of the basement material. Where there is a sufficient volume of shingle material the crest of the shingle beach will increase in elevation to accommodate sea level rise. Any such landward retreat rate will be extremely low along this coastline.

Areas of saltmarsh occur at the heads of many of the sea lochs. The effect on these areas depends heavily on the rate of sea level rise. For instance there appears to be a threshold value, where for rates below the threshold the saltmarsh surface is able to accrete and keep pace with the change. Above this threshold the marsh becomes submerged and is lost. There is also evidence to suggest that erosion and loss of saltmarsh is linked to increases in wave energy. Given that most of the saltmarsh areas occurring in Cell 5 are in the inner parts of deep sea lochs this is unlikely to be significant.

The extent of coastal edge retreat will vary all along the this coastline. In many of the beach areas, due to their stability, the effects will be minimal (compared to many other areas in Scotland). Although simplified predictions exist, (e.g. Bruun, 1983), actual retreat rates will depend upon a whole range of interrelating factors, the effects of which can not be assessed quantitatively. Such changes will be gradual, i.e. there will not be a sudden change in sea level, with the coastal regime gradually evolving due to these changes.

6.3.2 Impacts on man-made defences

<u>General</u>

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.

<u>Impact on man-made defences in Cell 5</u>
Little coastal defence work has been conducted within Cell 5. Based on the present defences it is unlikely that there will be any significant increase in the occurrence of damage to structures such as rock revetments in the short term due to the relatively small changes in the climate occurring. The main locations where such increases are likely to be most obvious are where present defences have a low factor of safety, but there do not appear to any structures which come under this category within this cell. It is highly unlikely there will be any noticeable increase in damage to defences other than 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 noticeable. Given that many of the town frontages are in relatively sheltered locations, or experience severe storm waves from a narrow direction sector, it is debatable whether this is likely to be a major problem in this cell.

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.

<u>Rainfall</u>
There is an observed variation in the rainfall pattern 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. Most

of the cliffs in cell 5 are relatively resilient to marine erosion and this is unlikely to be a significant problem.

- Increased river flows
  In many parts of the world, rivers still bring large quantities of sand and gravel to the coast, providing fresh supply. Increased river flows would increase the capacity of the river to transport sediment. This is unlikely to make have any significant impact upon the sediment budget within this cell.

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

In general the impact of climatic change is unlikely to have as great an influence upon the beach areas of this coastline as may potentially may occur on "softer" coastlines elsewhere. Any noticeable effects are likely to be localised. The magnitude of any change in one beach system may be entirely different from that experienced at a neighbouring beach due to the complex character of this coastline.

At present, the complexity of the coastal and nearshore zone makes it difficult to predict morphological changes due to the range of inter-relating 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 1-24

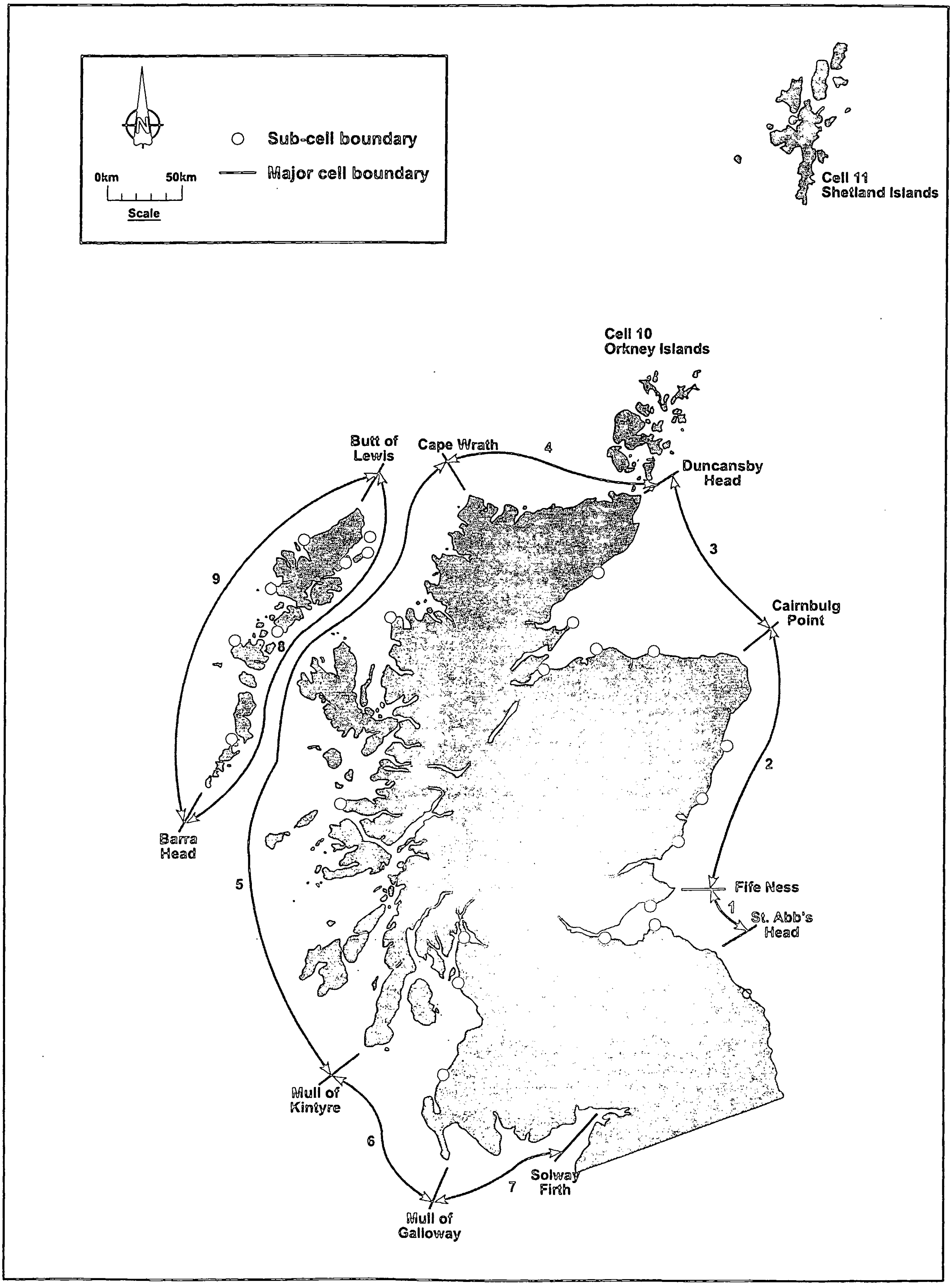


Figure 1 Coastal Cells in Scotland

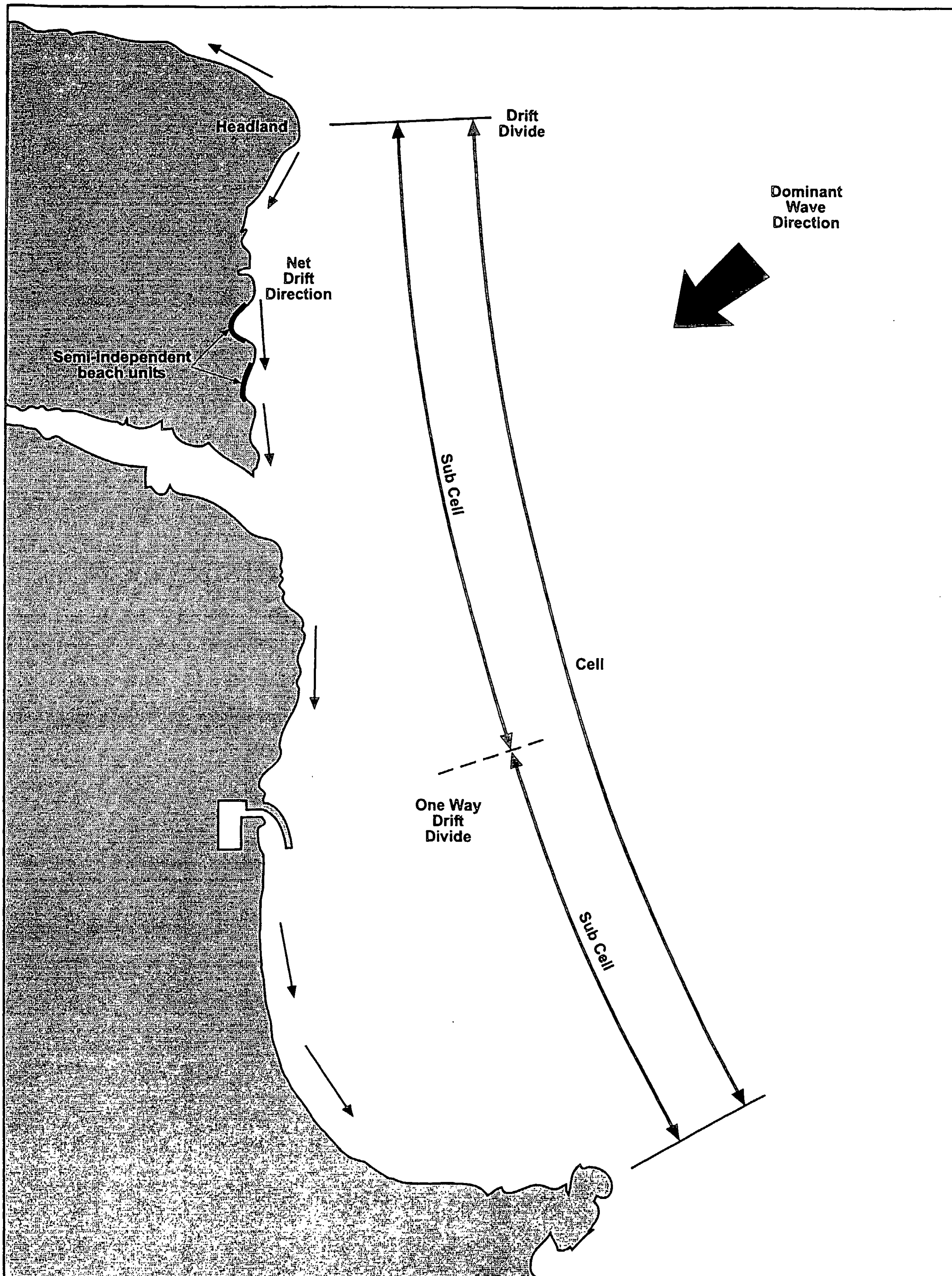


Figure 2 Idealised coastal cell

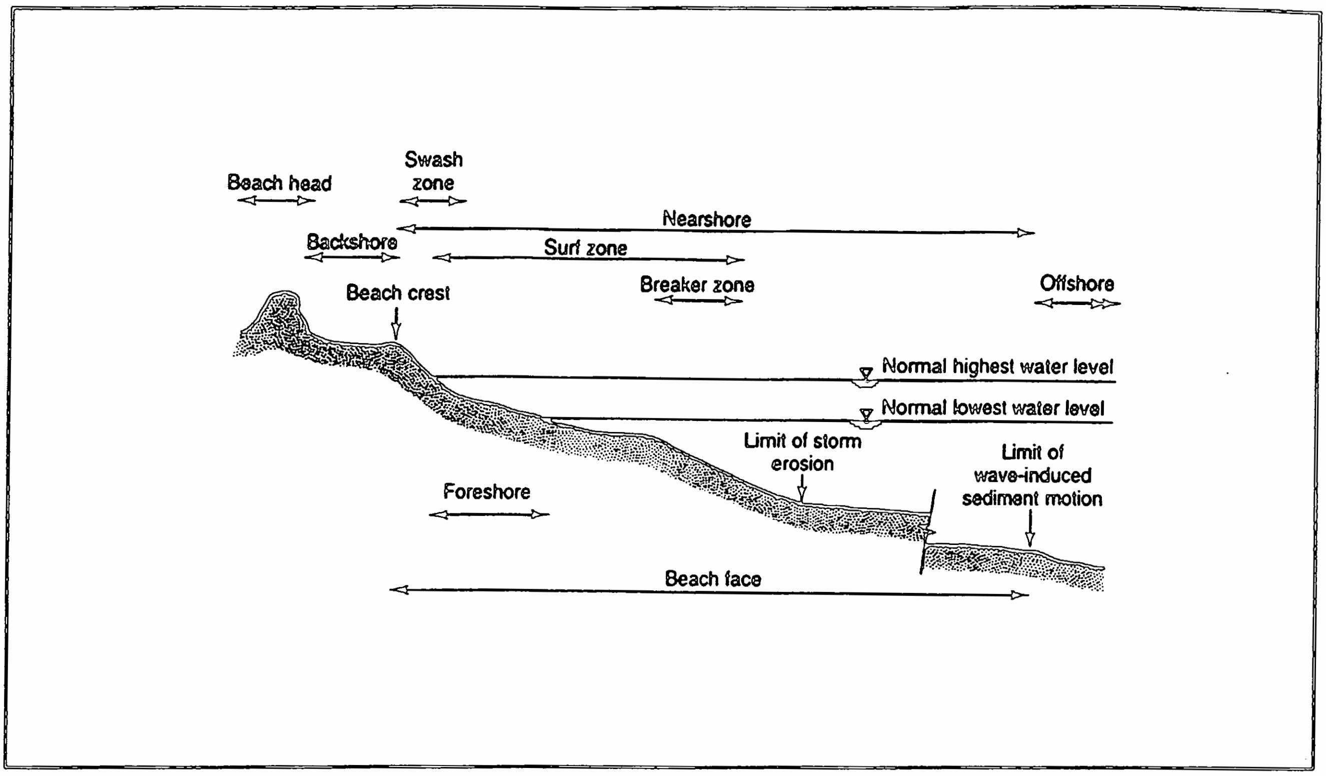


Figure 3 General beach profile and littoral zone

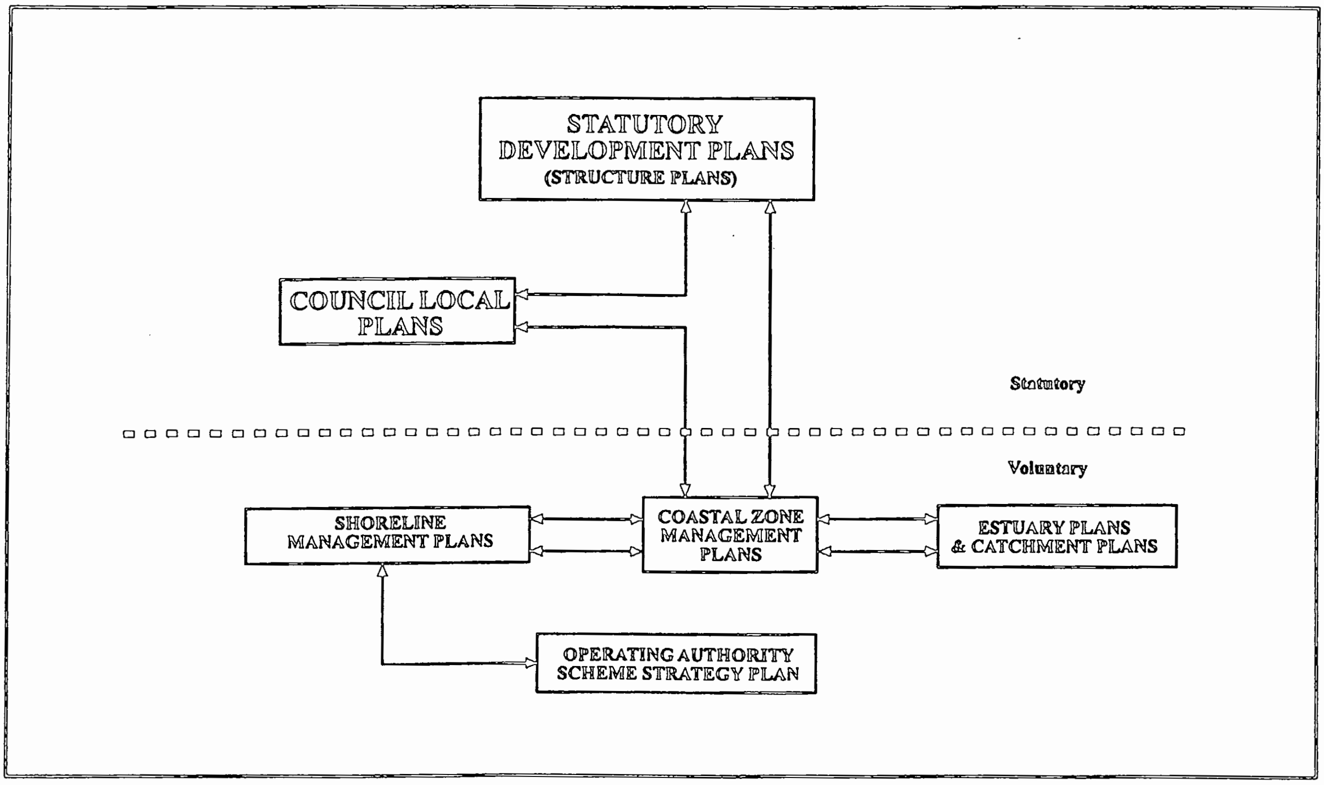


Figure 4 Relationship between coastal initiatives

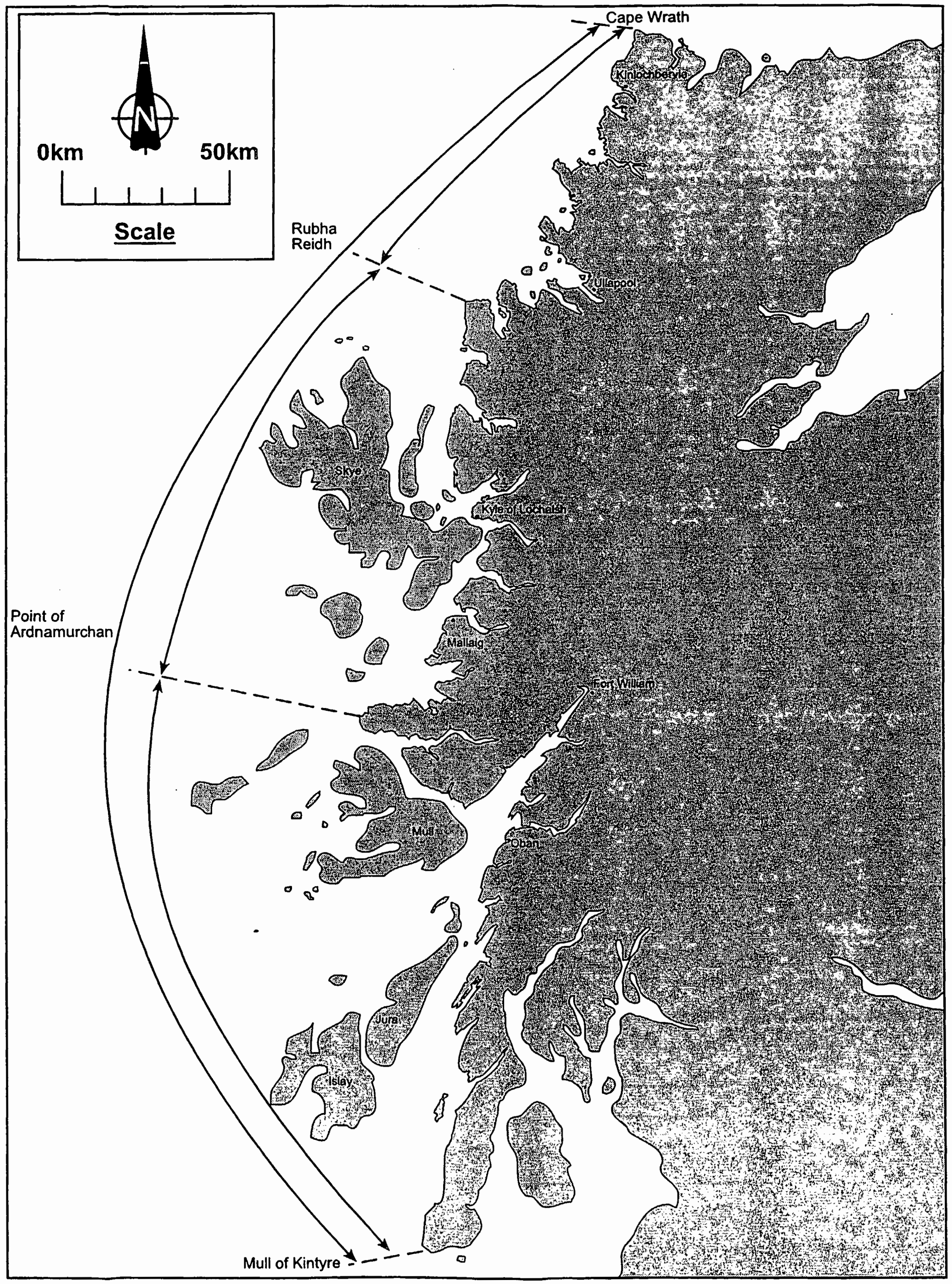


Figure 5 Cell 5 - Cape Wrath to the Mull of Galloway

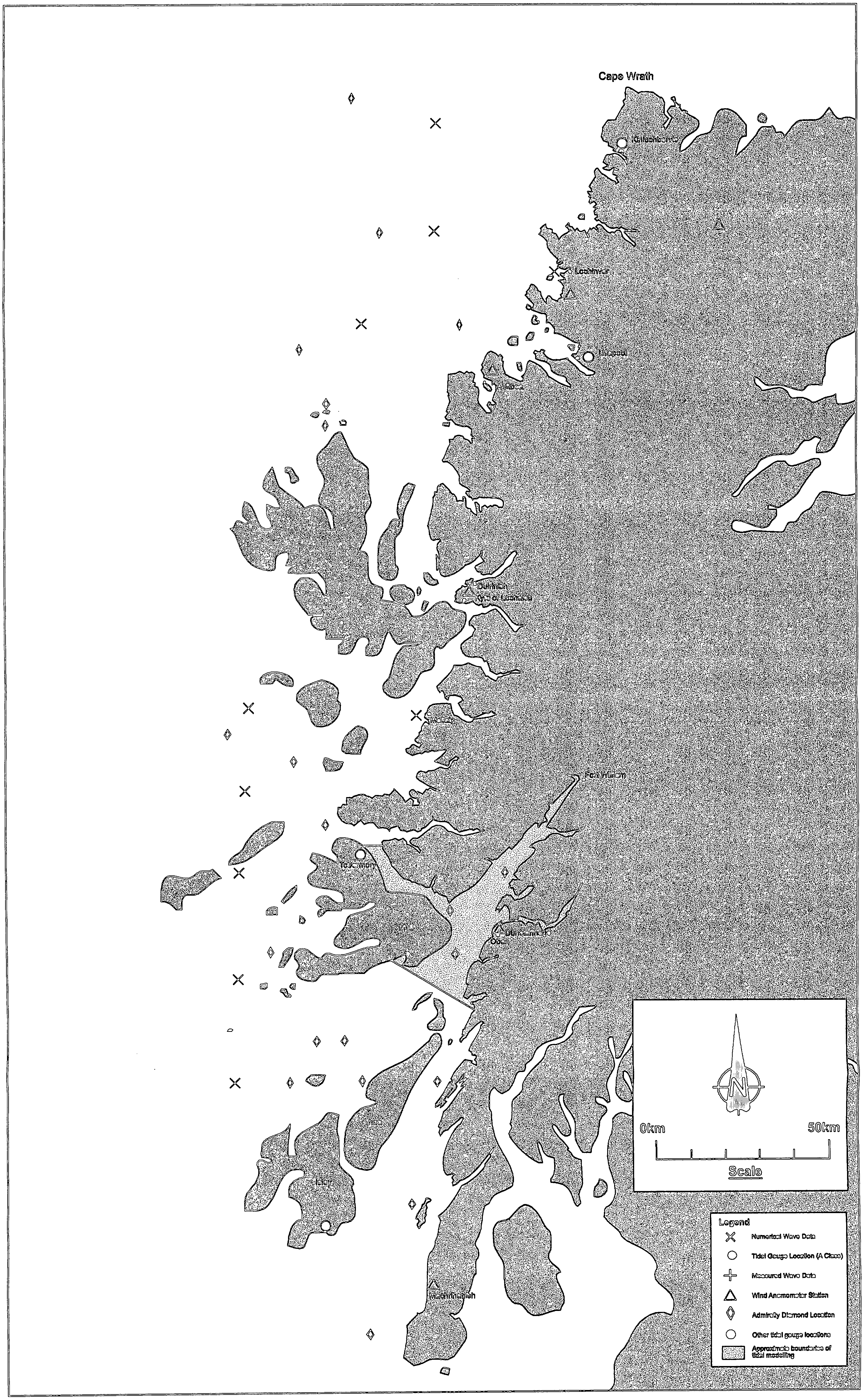


Figure 6 Cell 5 - Location of wind, tidal and wave data

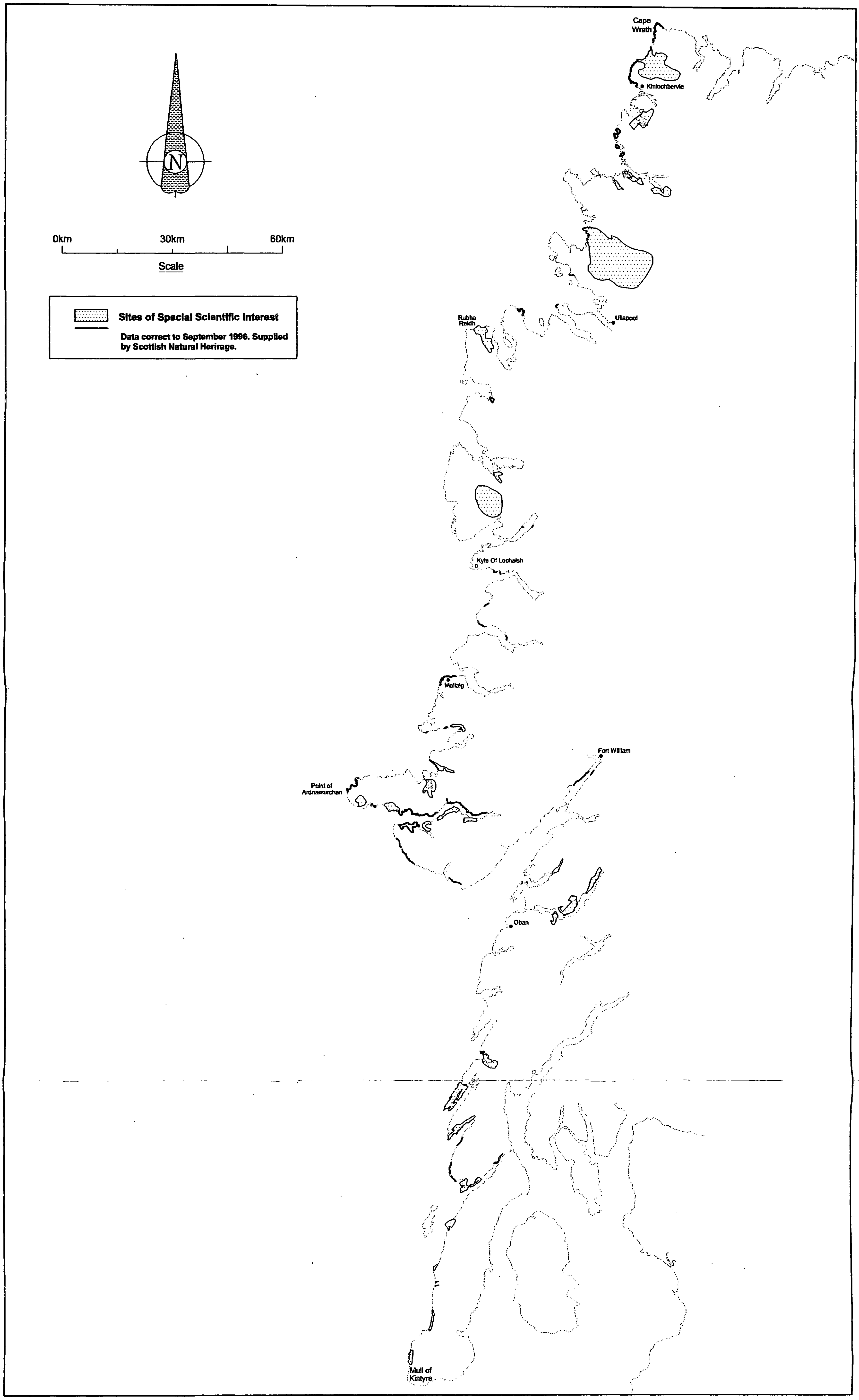


Figure 7 Cell 5 - Location of Sites of Special Scientific Interest

Figure 8 Cell 5 - Location of sites of natural heritage importance (other than SSSIs)

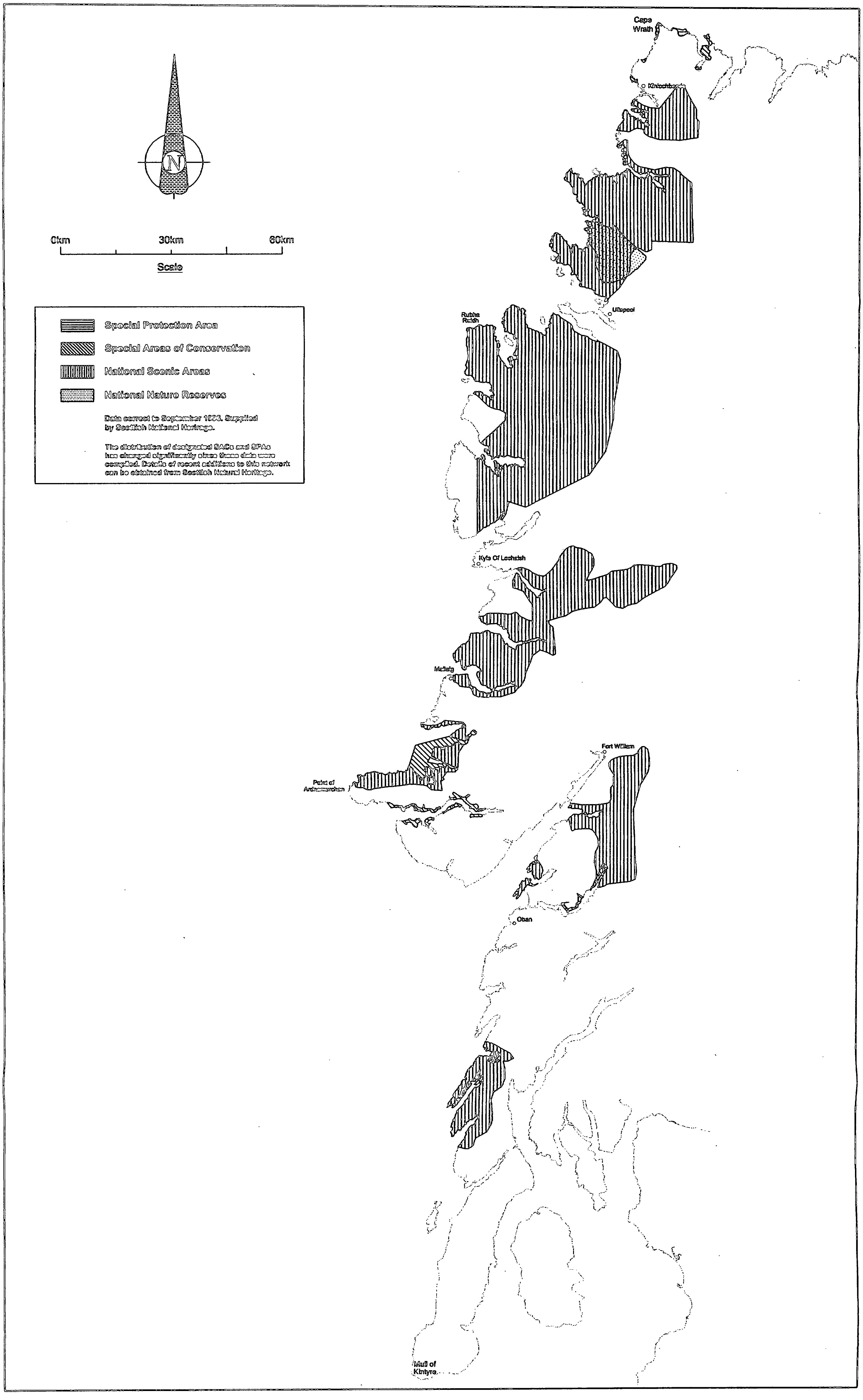


Figure 9 Cell 5 - Density of noted archaeological and historical sites

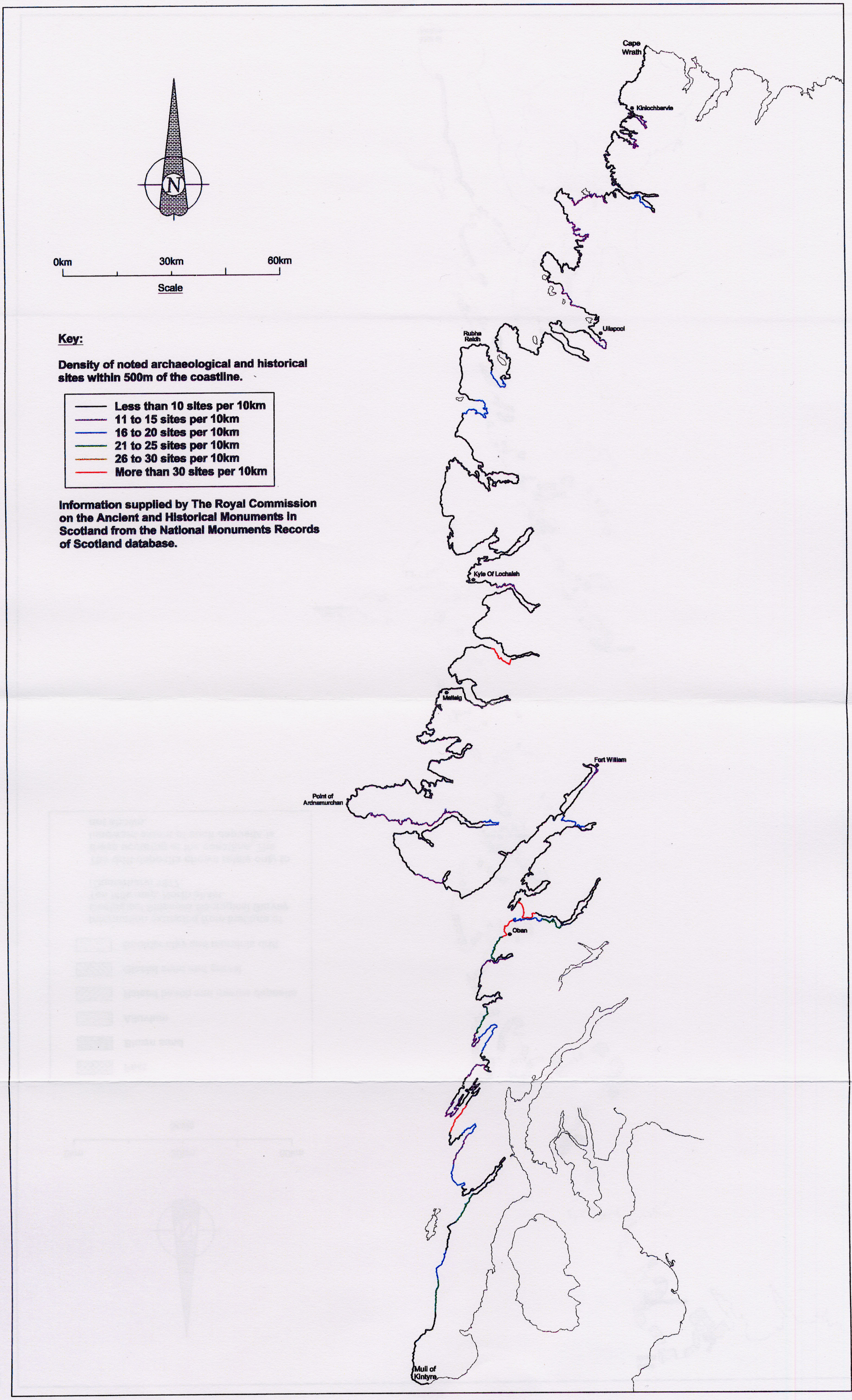
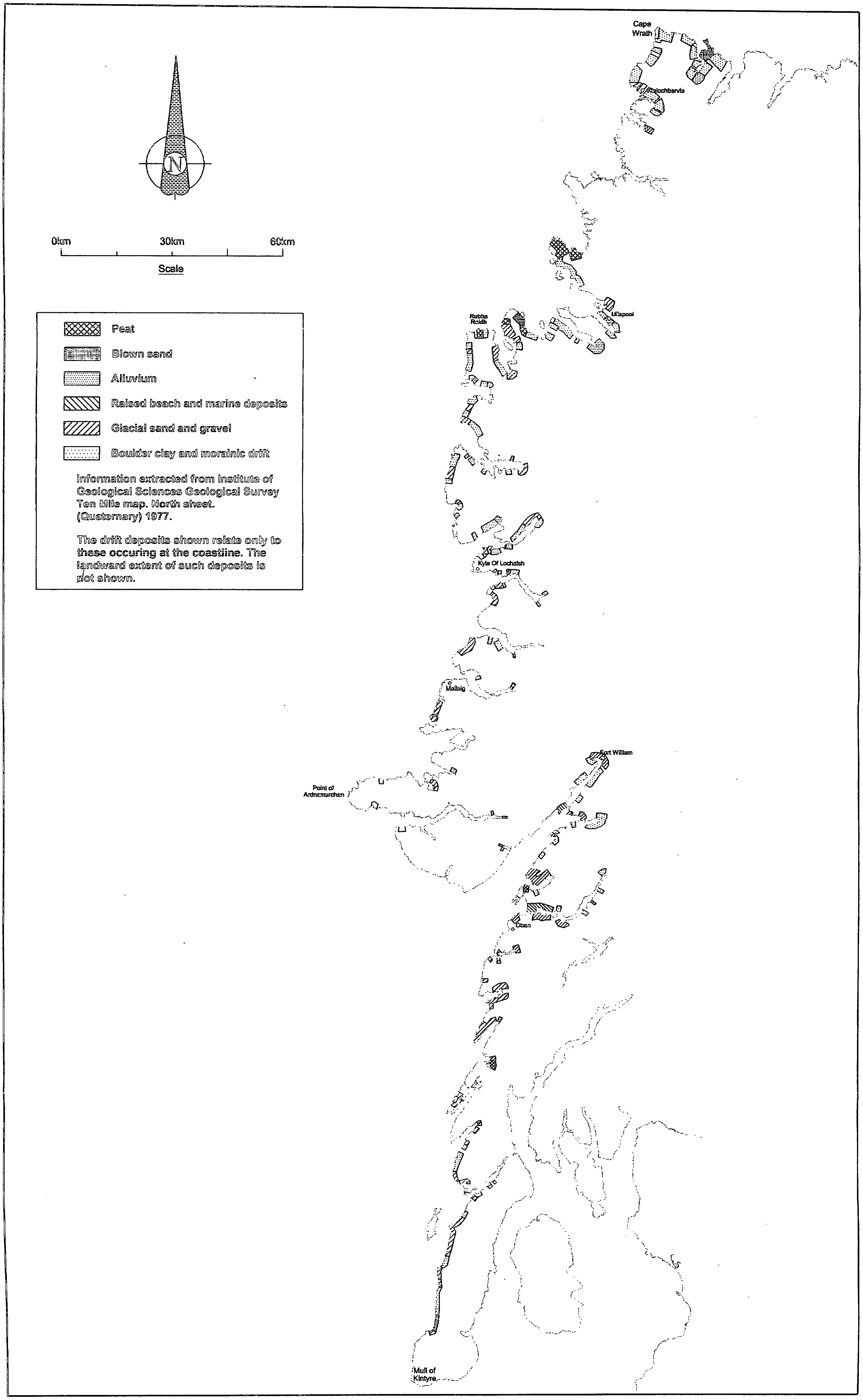


Figure 10 Cell 5 - Drift deposits



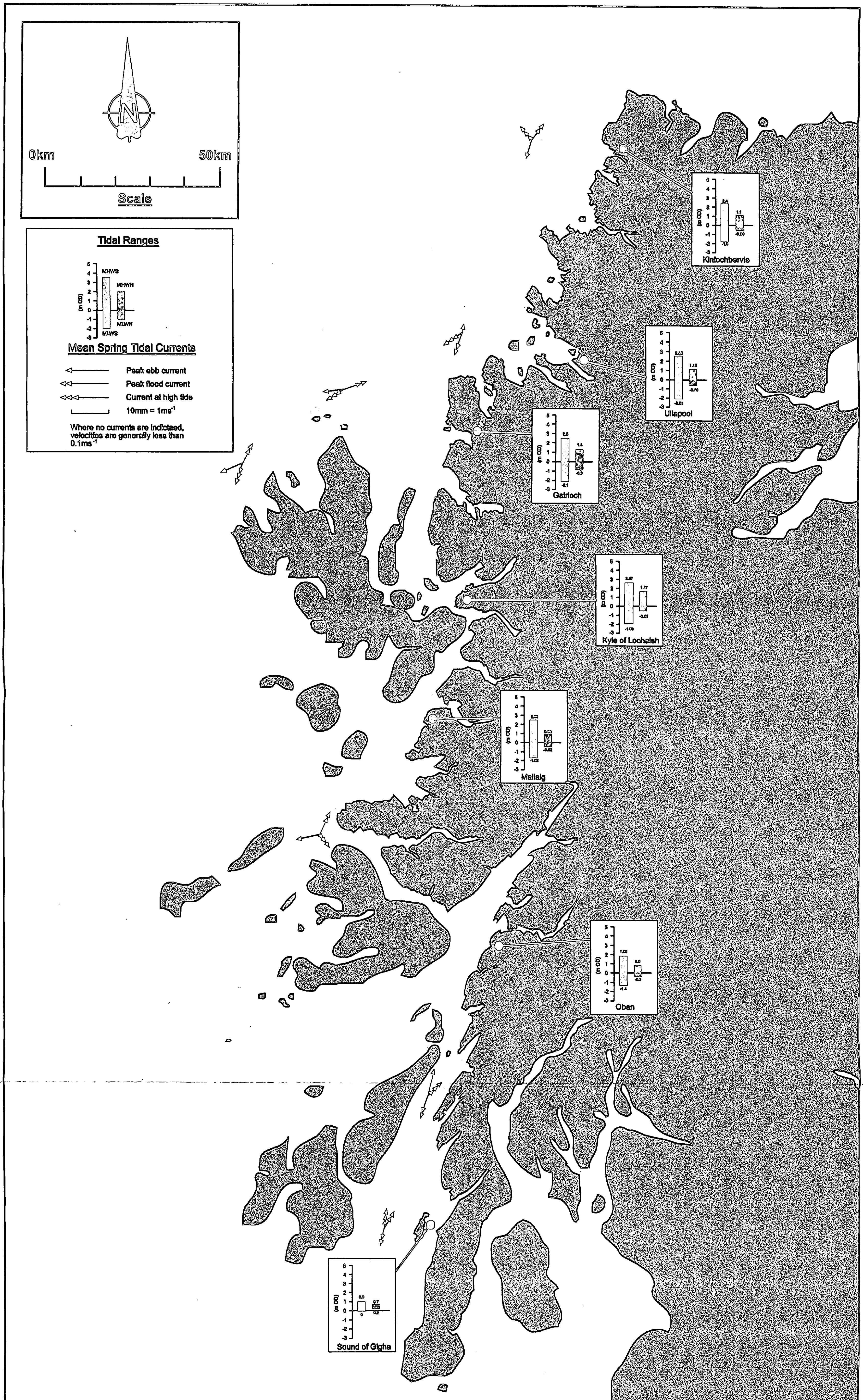


Figure 11 Cell 5 - Tidal levels and current information

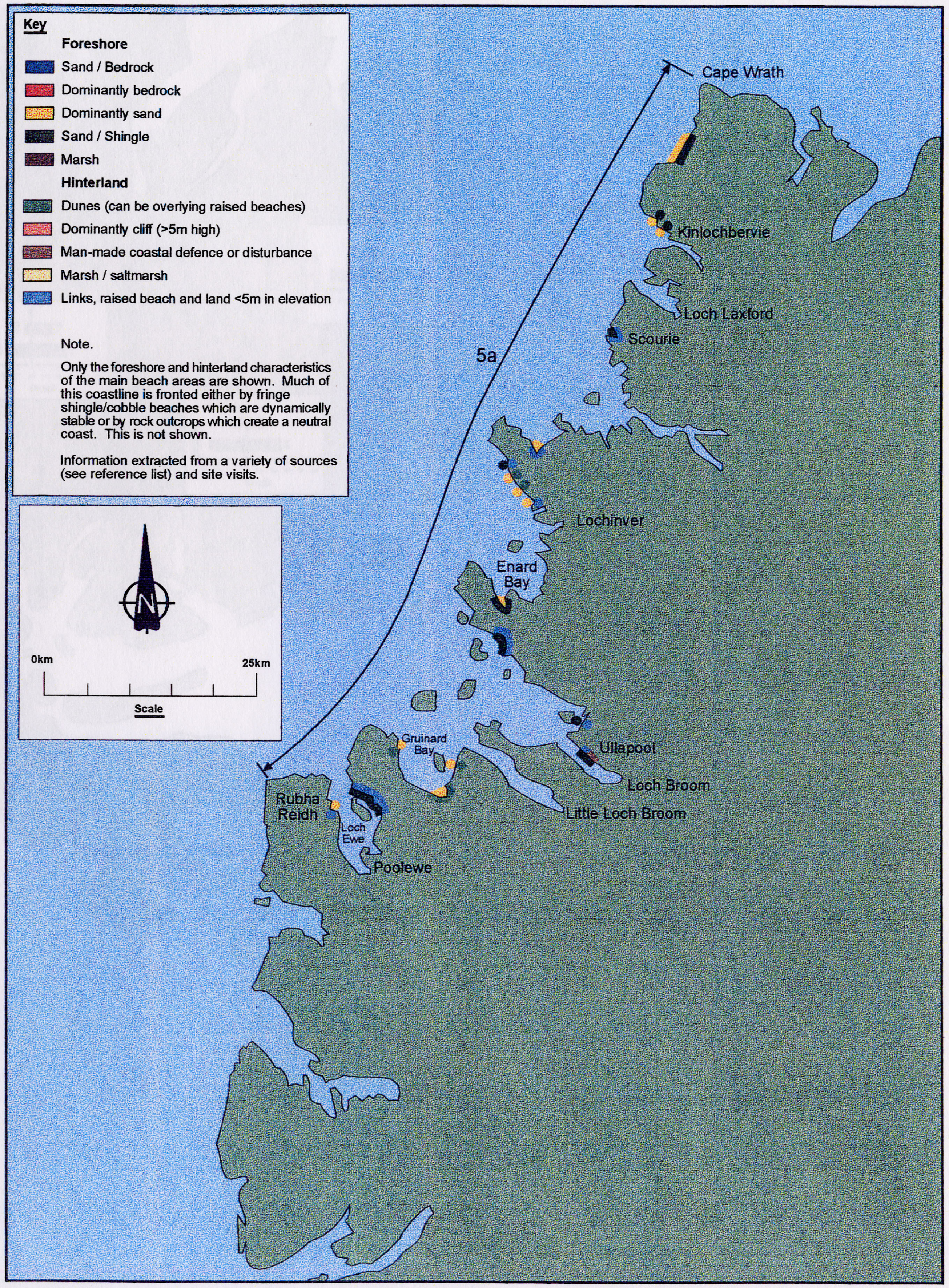


Figure 12 Cell 5a - Foreshore and hinterland characteristics

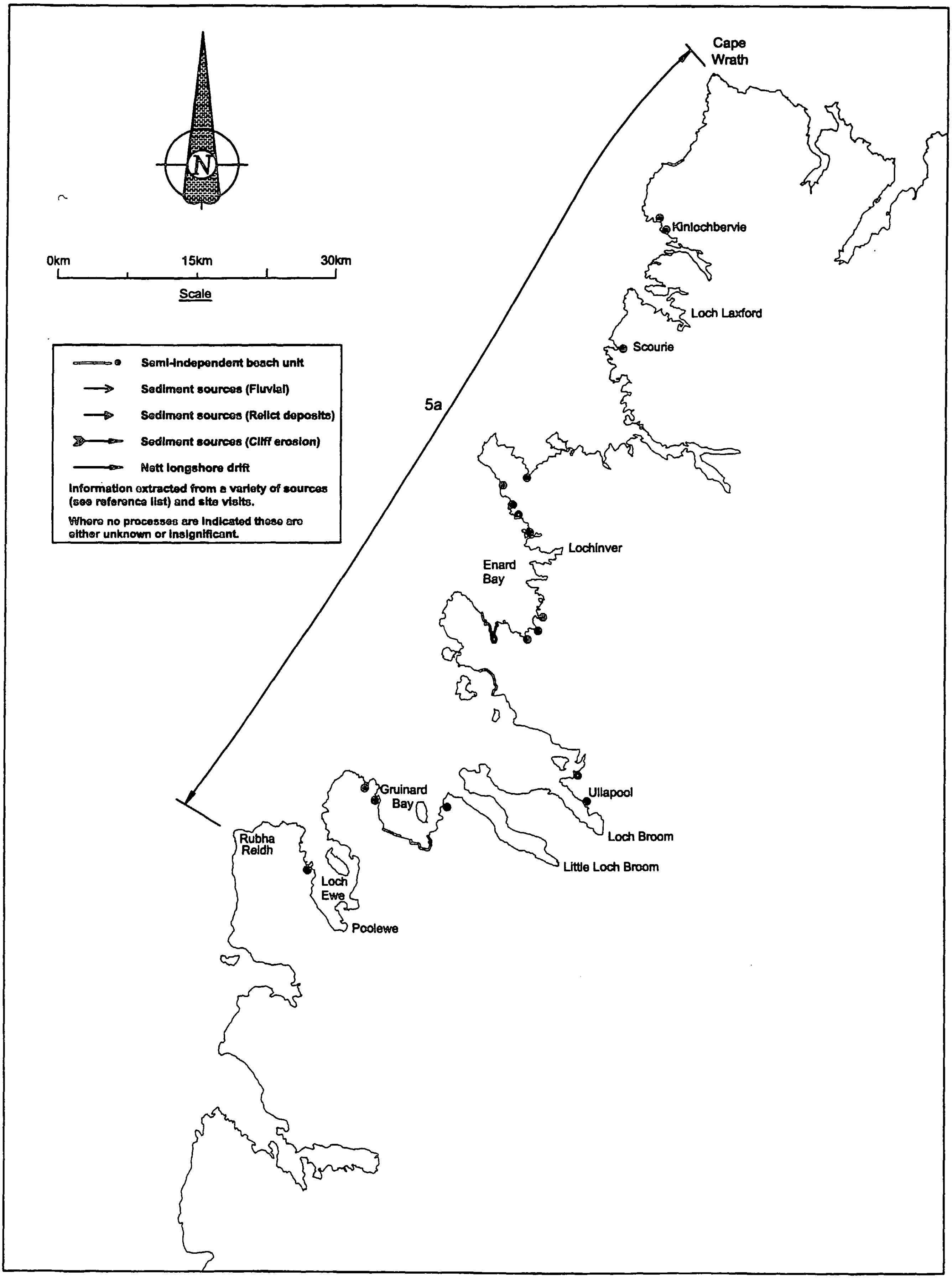


Figure 13 Cell 5a - Dominant littoral processes

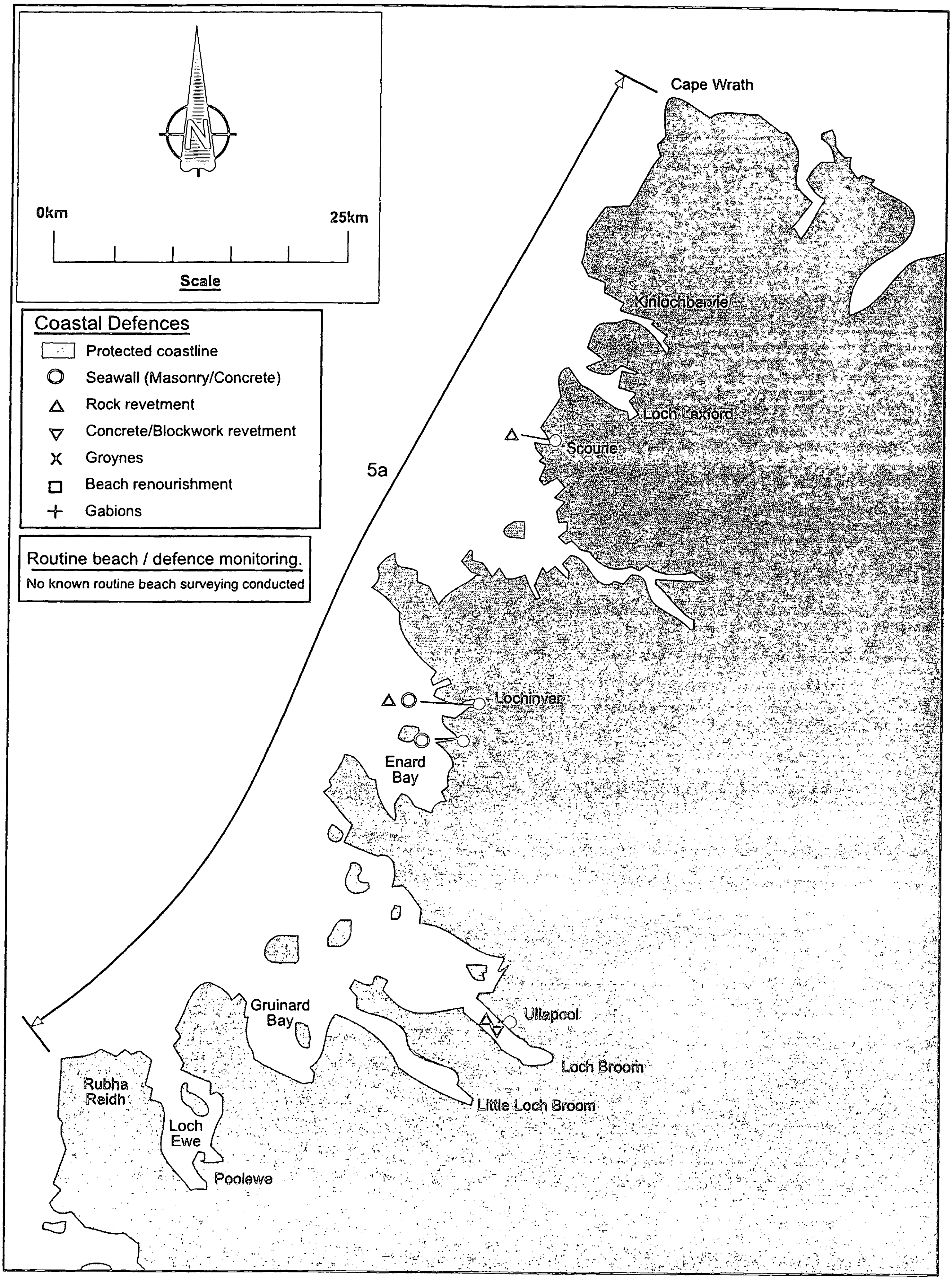


Figure 14 Cell 5a - Coastal defence and monitoring

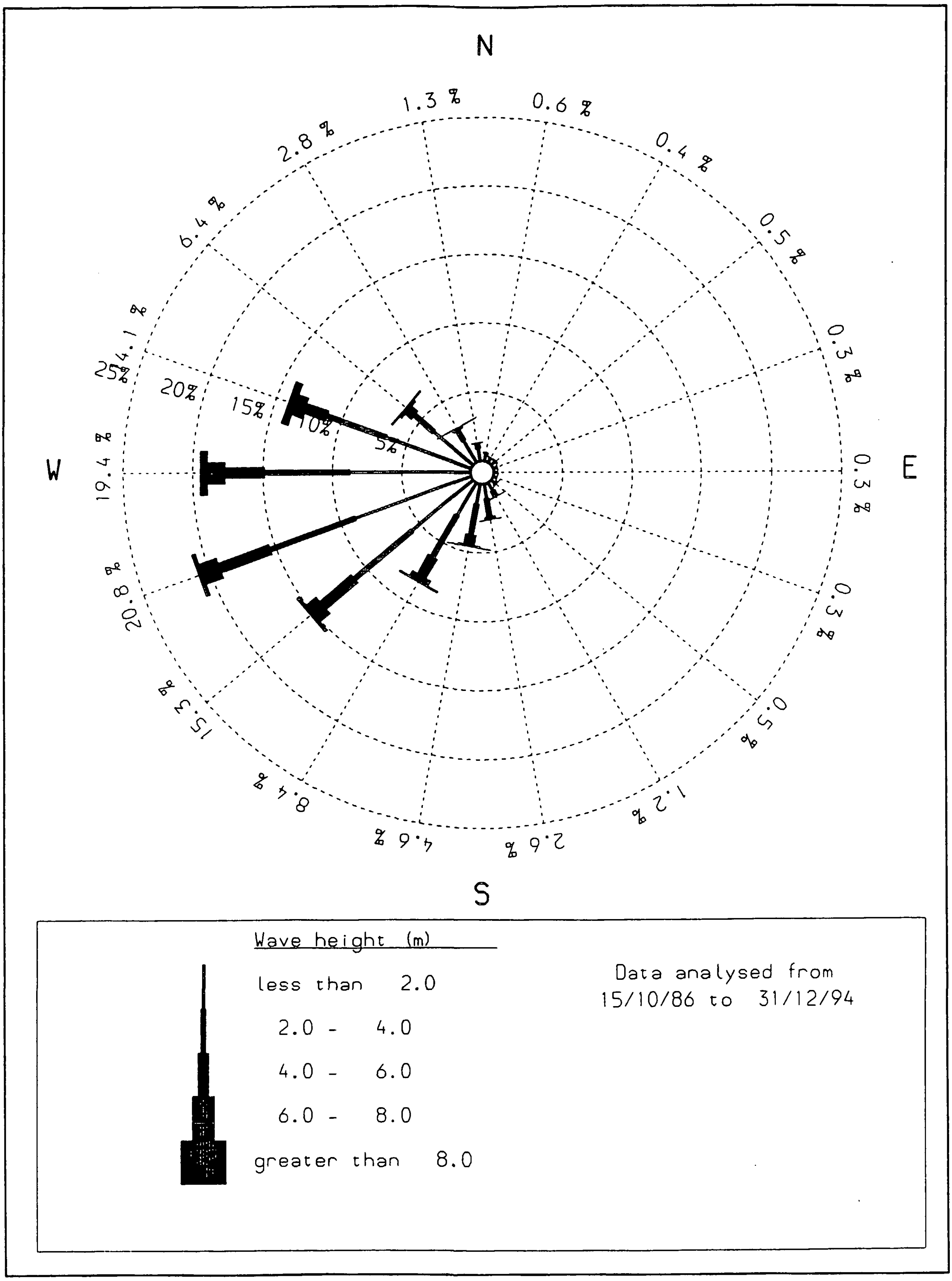


Figure 15 Total sea wave climate offshore of Sub-cell 5b

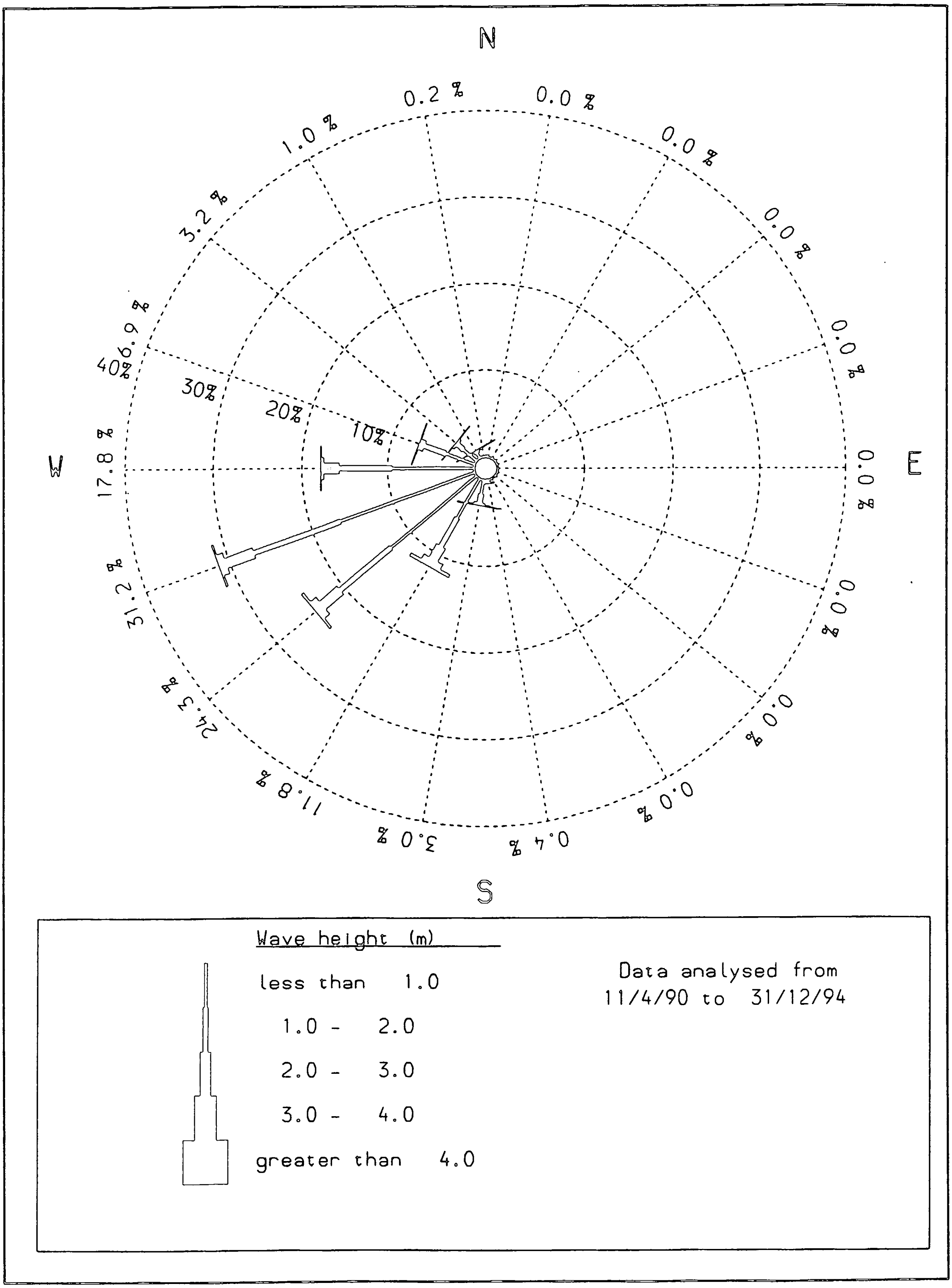


Figure 16 Swell sea wave climate offshore of Sub-cell 5b

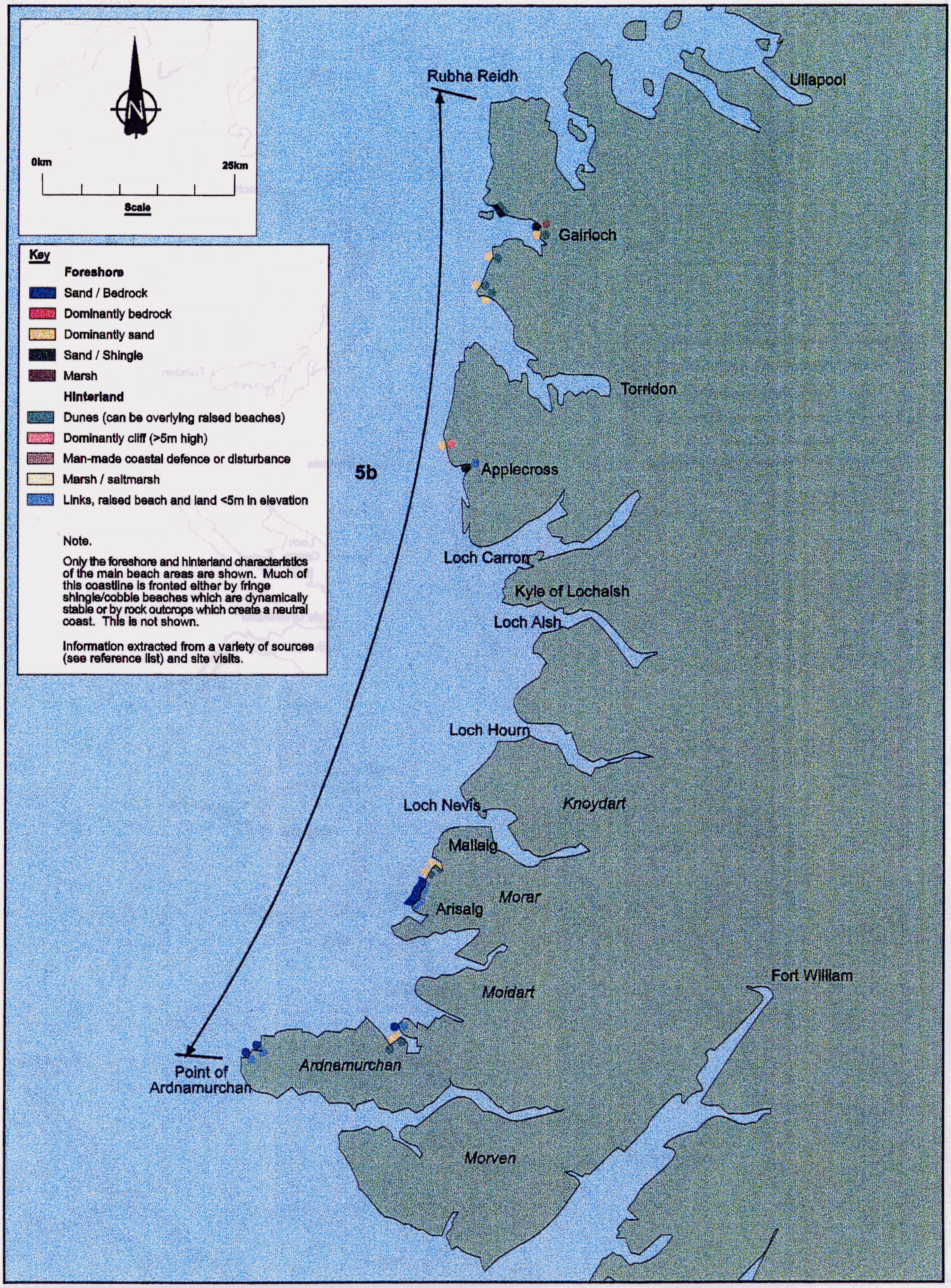


Figure 17 Cell 5b - Foreshore and hinterland characteristics

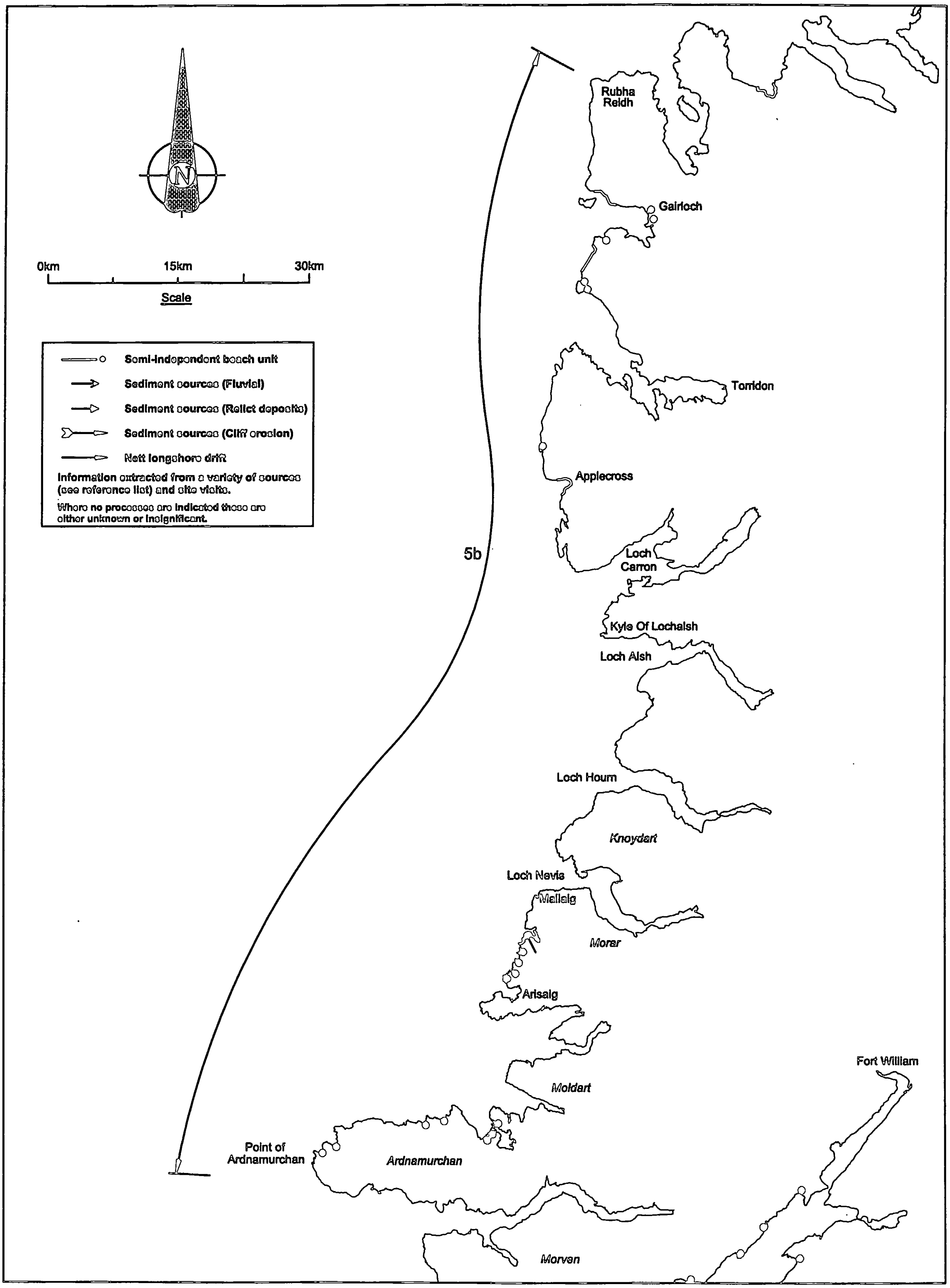


Figure 18 Cell 5b - Dominant littoral processes

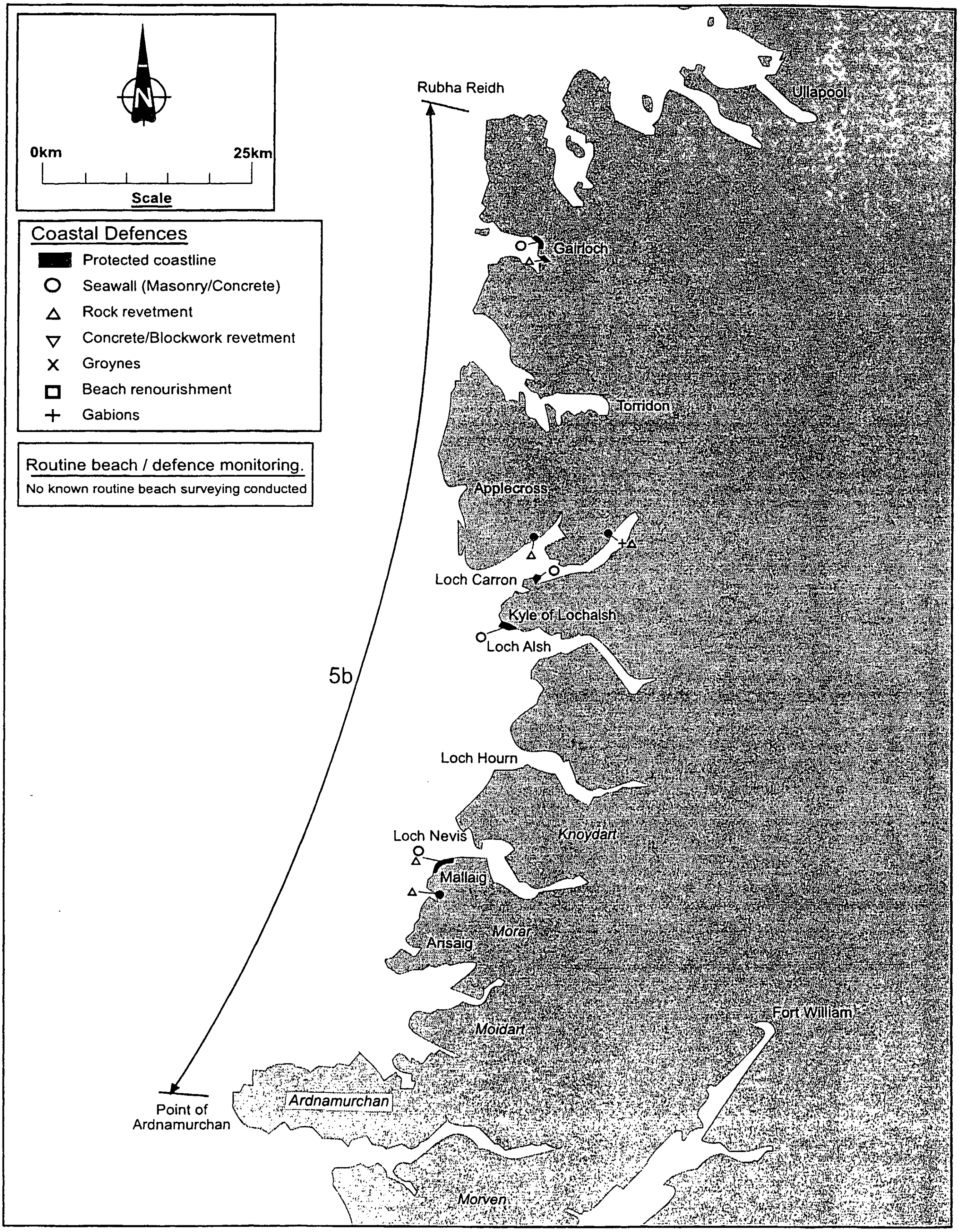


Figure 19 Cell 5b - Coastal defence and monitoring

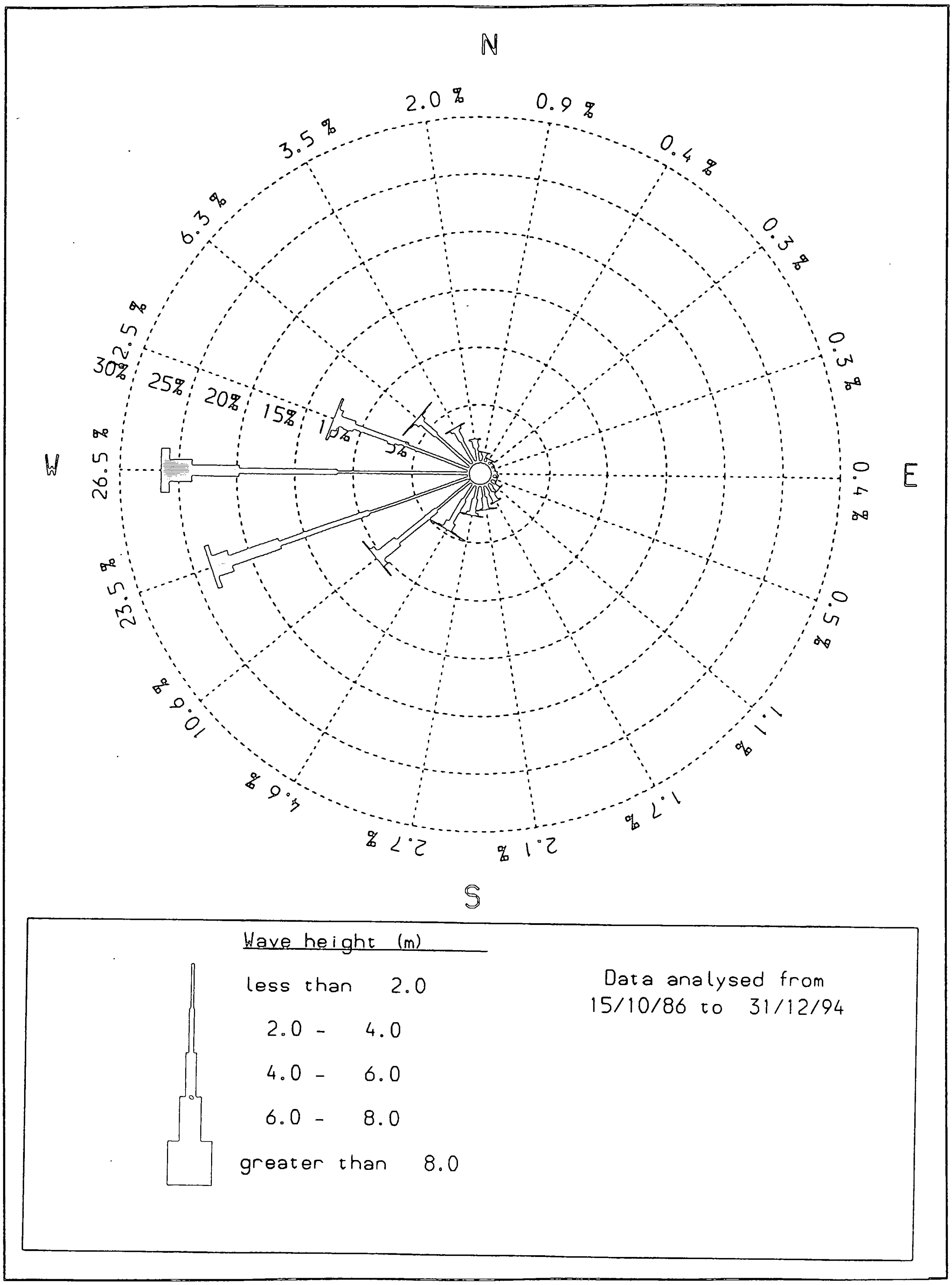


Figure 20 Total sea wave climate offshore of Sub-cell 5c

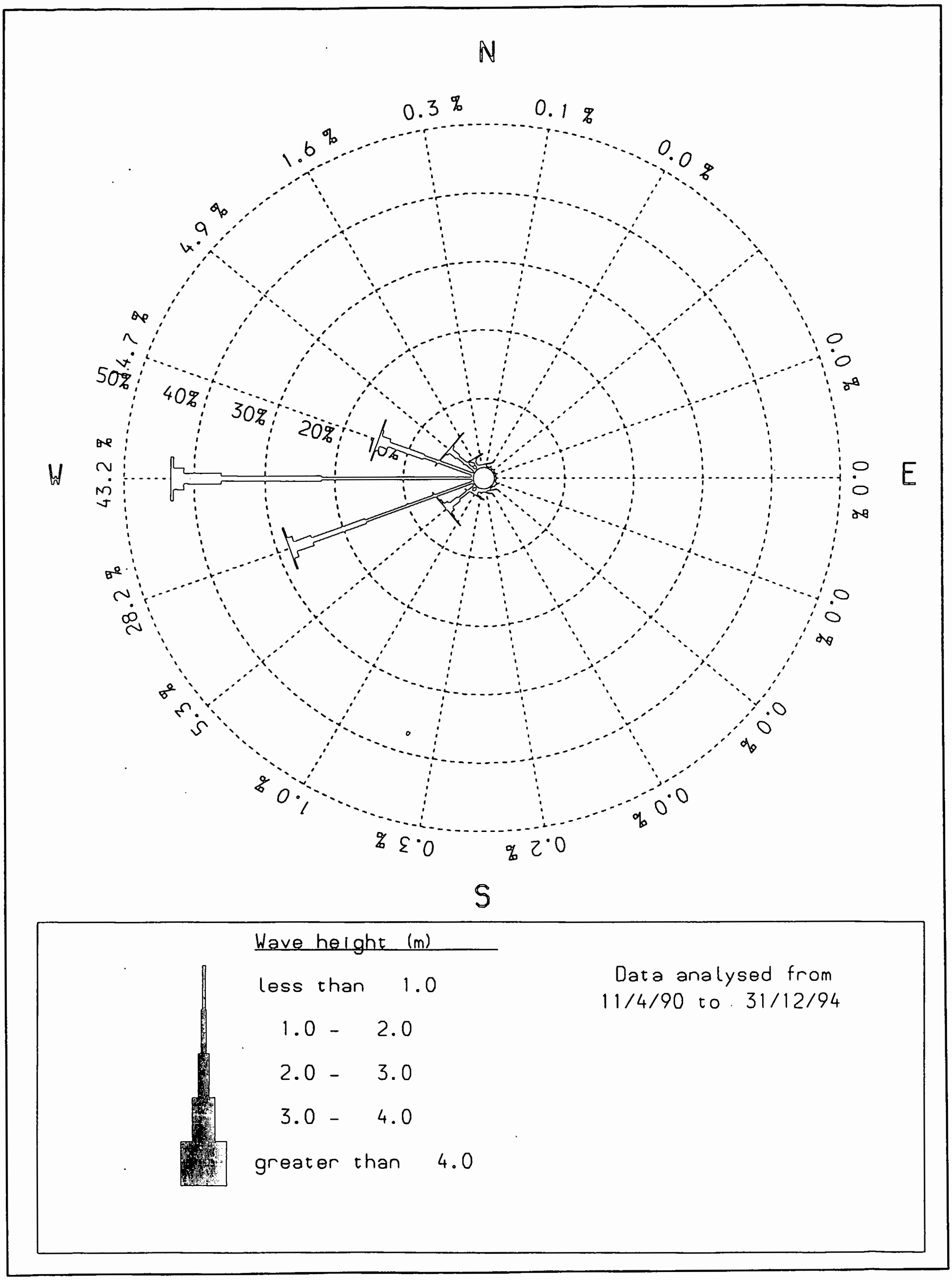


Figure 21 Swell sea wave climate offshore of Sub-cell 5c

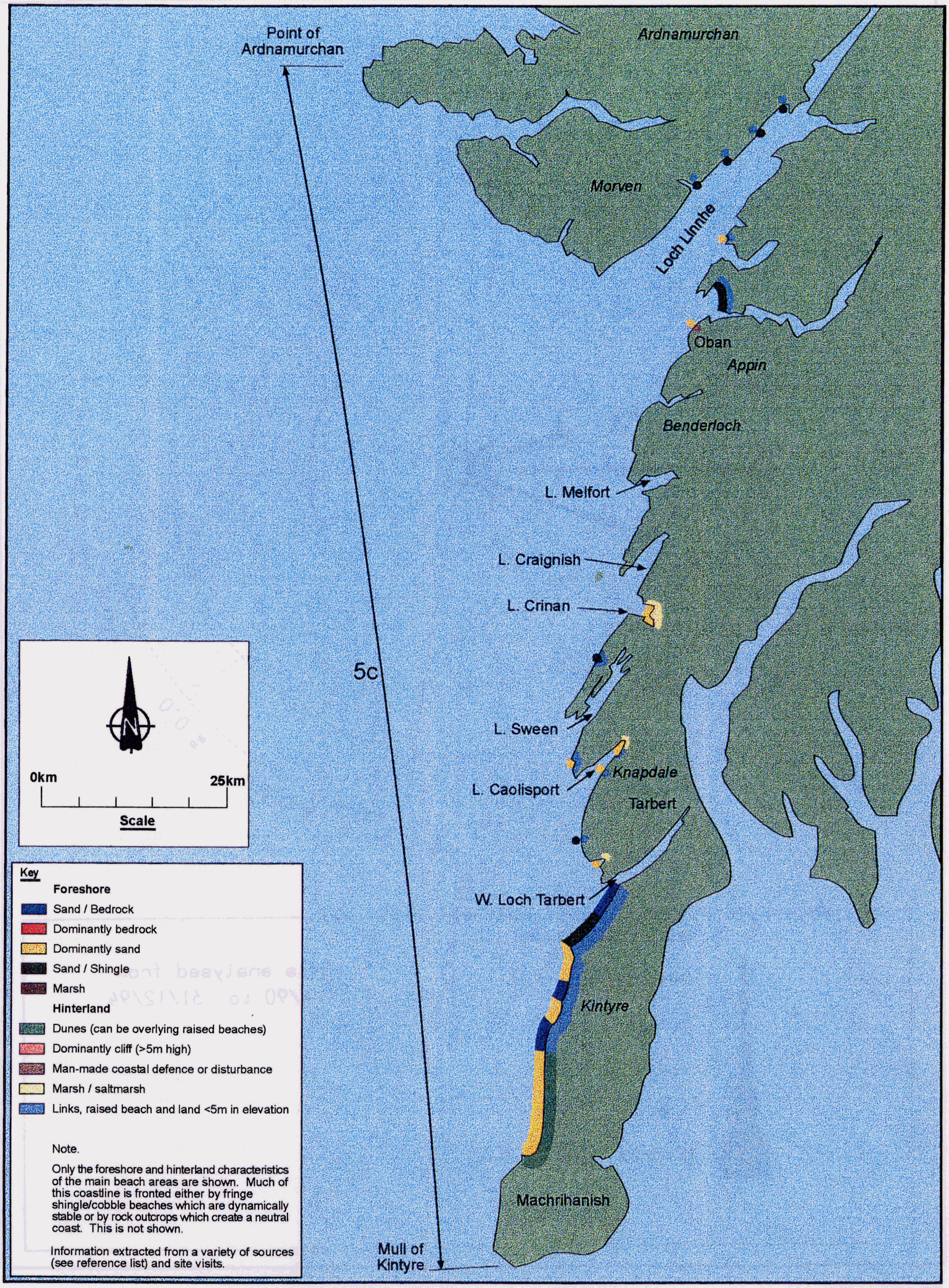


Figure 22 Cell 5c - Foreshore and hinterland characteristics

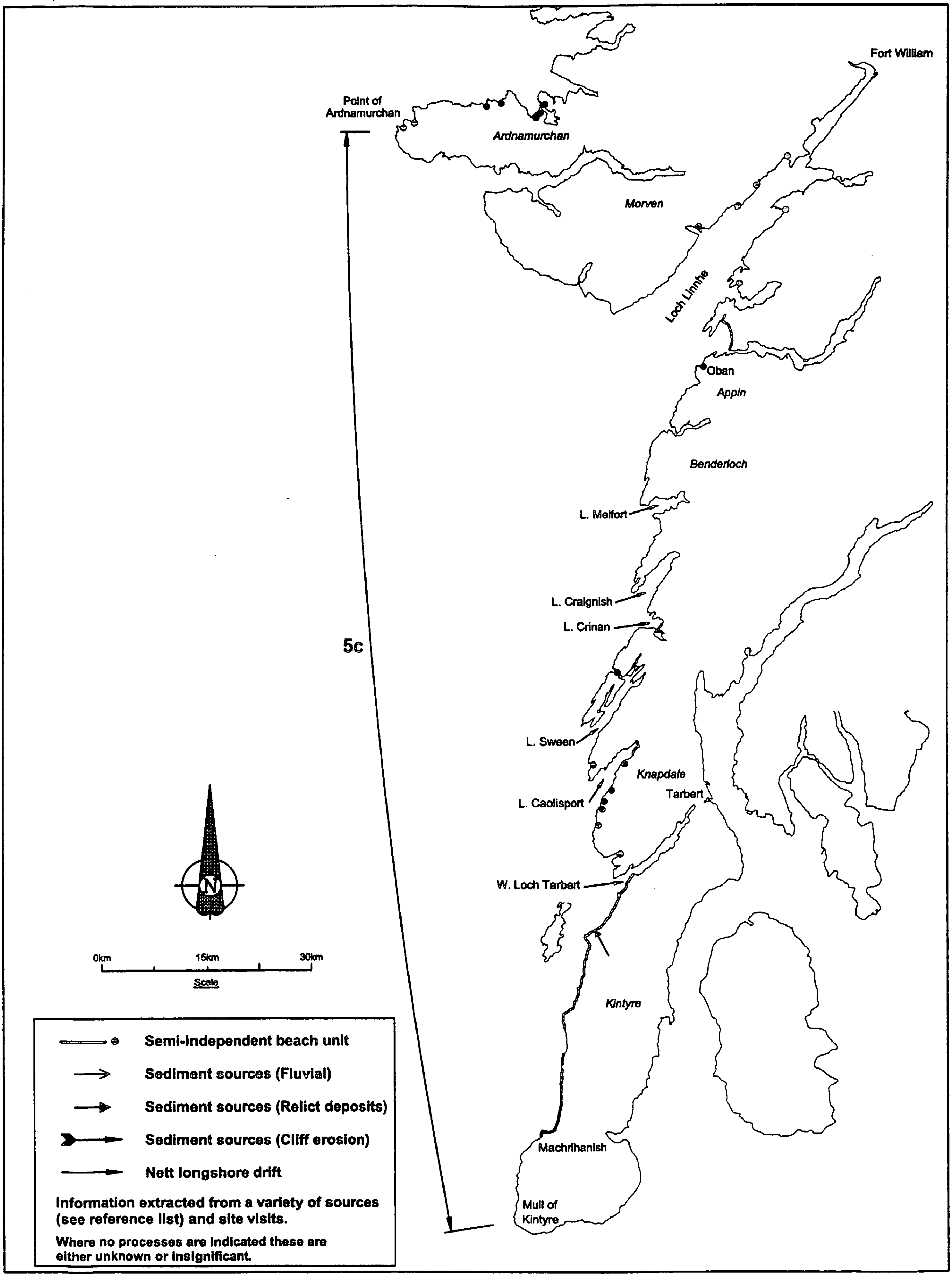


Figure 23 Cell 5c - Dominant littoral processes

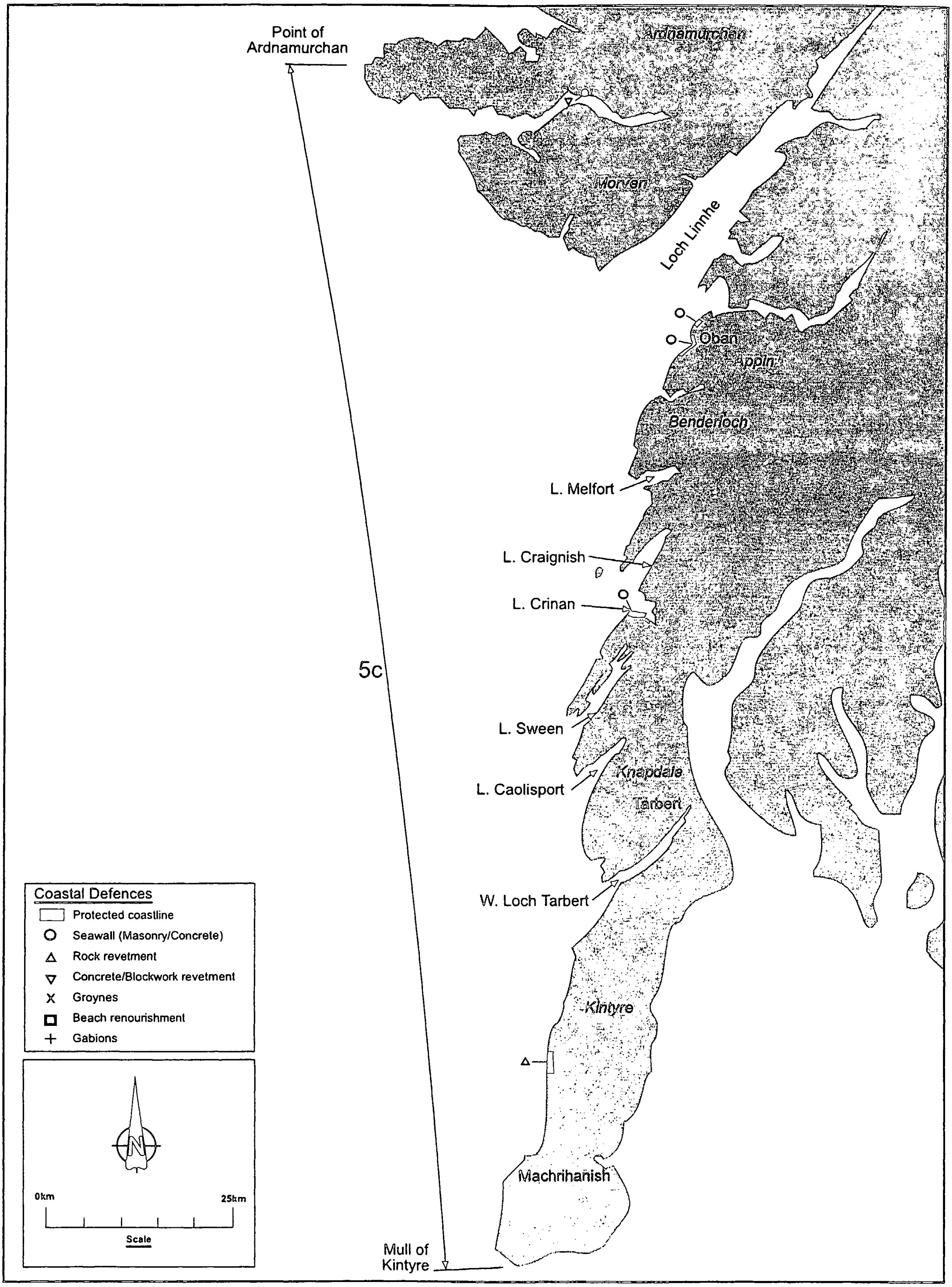


Figure 24 Cell 5c - Coastal defence and monitoring

Appendix 1 *Cell 5 - 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
Cape Wrath	NC260740	1014	1990	Maritime heath Montane heath Seabirds breeding
Southern Parphe	NC250630	5314	1990	Sand dunes Sea cliff(soft rock) Dry grassland Maritime heath Montane heath Peatland Phragmites reedbed Lower plants Waders breeding Wildfowl breeding Comments: Breeding birds: dunlin; golden plover & and red - throated diver
Sheigra -Oldshoremore	NC192589	254.7	1987	Sand dunes Machair Maritime heath Flush or seepage line Scrub Lower plants
Loch Laxford	NC217486	1163	1949	Geological interest
Scourie Coast	NC143446	214.9	1989	Geological interest
Rubha Dunan	NC028070	22.9	1989	Geological interest Open water Wet grassland/grazing marsh Woodland Fen Phragmites reedbed Lower plants Comments: two separate areas one coastal and geological
Cailleach Head	NG985985	9.4	1988	Geological interest
Aultbea	NG890975	79	1988	Geological interest
Carn A'Bhealaich Mhoir	NG826324	39.2	1985	Geological interest.
Slumbay Island	NG896385	7.5	1988	Geological interest.
Attadale	NG913376	6.6	1989	Geological interest Lower plants.
Ard Hill	NG818265	22.8	1984	Geological interest
Avernish	NG834262	24	1984	Geological interest
Allt Cracaig Coast	NG793173	43.4	1985	Geological interest
Eilean Chlamail - Camas nan Ceann	NG773128	26.1	1985	Geological interest

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Rubha Camas Na Cailnn	NG852084	26.7	1984	Geological interest
Mallaig Coast	NM684977	50	1981	Geological interest
Druimindarroch	NM688842	13.2	1986	Geological interest
Loch Moidart	NM672734	798.8	1986	Geological interest Tidal flats Open water Saltmarsh Wet grassland/grazing marsh Woodland Peatland Flush or seepage line Lower plants Terrestrial invertebrates
Kentra Bay & Moss	NM650685	998.7	1990	Saltmarsh Maritime heath Woodland Lower plants Terrestrial invertebrates Site used for wintering wildfowl. Locally important. Site used by other wintering bird species Comments: Greenland white-fronted geese
Salen to Woodend	NM738633	763.9	1990	Saltmarsh Maritime heath Woodland Peatland Lower plants Marine biological interest Terrestrial invertebrates Mammals noted
Ben Hiant & Ardnamurchan Coast	NM600610	1574.7	1989	Geological interest Saltmarsh Woodland Lower plants Terrestrial invertebrates Mammals noted Seabirds breeding
Inninmore Bay	NM719423	127.2	1986	Geological interest Wet grassland/grazing marsh Dry grassland Woodland Phragmites reedbed Lower plants
Callert	NN074595	11.7	1988	Geological interest
St. John's Church	NN065587	2.4	1988	Geological interest
Lynn of Lorne Small Islands	NM860400	97.6	1986	Dry grassland Woodland Scrub. Mammals noted Seabirds breeding Comments: breeding common seals
Clach Tholl	NM899448	7.5	1990	Geological interest
South Shian & Balure	NM909422	9.2	1990	Geological interest

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
South Kerrera & Gallanach	NM794279	83.3	1989	Geological interest
Moine Mhor	NR815925	1194.8	1990	Geomorphological interest Saltmarsh Wet grassland/grazing marsh Woodland Peatland Lower plants Terrestrial invertebrates Waders breeding Site used for wintering wildfowl. Locally important Site used by other wintering bird species
Taynish Woods	NR735850	390.1	1990	Open water Saltmarsh Woodland Fen Lower plants Marine biological interest Terrestrial invertebrates Comments: 150 lichen spp.; wildcat
West Tayvallich Peninsula	NR706834	662	1992	Geological interest
Ulva, Danna & The McCormaig Isles	NR700799	742.5	1992	Tidal flats Coastal lagoon Saltmarsh Dry grassland Maritime heath Woodland Fen Scrub Lower plants Marine biological interest Terrestrial invertebrates Mammals noted Wildfowl breeding Seabirds breeding Site used for wintering wildfowl. Internationally important. Comments: otters, seals, white-fronted and barnacle geese
Kilberry Coast	NR716690	214	1986	Rocky shore Sand dunes Sea cliff(hard rock) Peatland Scrub
Ardpatrick & Dunmore Woods	NR765610	751	1986	Geological interest Tidal flats Dry grassland Maritime heath Woodland Fen Lower plants Terrestrial invertebrates Mammals noted Seabirds breeding Comments: grey & common seals haulout; wildcat
Glenacardoch Point	NR660379	81.5	1990	Geological interest

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Bellochantuy & Tangy Gorges	NR657278	21.4	1986	Geological interest
Machrihanish Dunes	NR653238	299	1986	Sand dunes Mammals noted.
Dun Ban	NR595141	247.7	1985	Sea cliff(hard rock) Scarce or rare plants Seabirds breeding

Appendix 2 Cell 5 - 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
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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)
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Scottish Environment Protection Agency
Erskine Court
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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
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Scottish Natural Heritage
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Scottish Trust for Underwater Archaeology
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University of Edinburgh
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Scottish Tourist Board
23 Ravelston Terrace
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Tel: 0131-332 2433
Fax: 0131-343 1513

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

Tel: 01344 420242
Fax: 01344 854412

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

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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.