

chapter

2

**Geography, hydrography
and climate**

2.1 Introduction

This chapter gives a concise account of physical features characterising the coasts and offshore areas of Region III. The first two sections (2.2 and 2.3) deal with the geography and geology of the region concentrating on the coasts and the extent to which they have been developed by human activity. Subsequent sections (Sections 2.4 to 2.10) describe the hydrographic and climatic conditions that play a dominant role in shaping the substrates, habitats and natural resources of the region. Finally, Section 2.11 identifies a number of areas (OSPAR 'focus areas') within the region that, due to a combination of physical, biological and anthropogenic influences, are especially vulnerable to changes that may, in the long-term, degrade or devalue the indigenous resources and ecosystems.



2.2 Description of the coastal margin

A Celtic Seas Coastal Directory is being prepared jointly by the UK and Ireland and is expected to be published in 2000. The directory will give details of the geology, ecology and various human activities around the coasts. The brief descriptions given below follow a series of adjacent coastal sectors (*Figure 2.1*), starting with the western seaboard of Great Britain and continuing with the whole island of Ireland. The boundaries of the coastal sectors referred to in this section are marked on *Figure 2.1* by a short line transecting the coast.

Cape Wrath to Ardnamurchan Point: This is the most northerly section of the coastline, extending from

Cape Wrath at the north-west corner of Scotland to Ardnamurchan Point, just north of the Isle of Mull and the most westerly point of the mainland. This coast, comprising a series of fjordic sea lochs and rocky headlands with cliffs and areas of sand dunes, is one of the least impacted in the UK, although in recent years there has been extensive development of mariculture operations. Offshore, the Western Isles have low but deeply shelving coastlines with rocky embayments and pocket dunes. The western coasts of the Hebrides are very exposed to the Atlantic and some areas may experience gales on as many as 50 days each year. There is a diversity of coastal habitats and scenery, changing markedly over short distances.

Figure 2.1 Coastal features of Region III.



Ardnamurchan Point to Corsewall Point: The northern part of this coast is deeply indented by fjordic inlets (sea lochs) arising from the glacial deepening of valleys during the Pleistocene Period. These inlets afford sheltered areas extensively exploited for mariculture. The geology is dominated by Dalradian schists and igneous rocks and consequently the shoreline is scenically dramatic and resistant to erosion. To the south and west there are numerous offshore islands of which the largest are Arran, Jura, Islay and Mull. From the Clyde Estuary southwards the coastline is relatively unindented and of low relief.

Corsewall Point to Colwyn Bay: This section includes the coasts of south-west Scotland, Cumbria, the Isle of Man, Solway Firth, Liverpool and Morecambe Bays and the north-east coast of Wales. From Corsewall Point to the Solway Firth much of the coastline is rocky whereas further south the hinterlands are low-lying and the shoreline is characterised by numerous sand and shingle beaches. The section contains fourteen estuaries comprising almost a quarter of the total estuarine area of the UK; all except one occupy more than 5000 ha. Morecambe Bay has one of the largest areas of intertidal mud and sand in the UK, second only to the Wash (on the east coast of Great Britain). The estuarine coast in the south of this sector is one of the most highly developed in Region III. There are major industrial and port facilities on both banks of the Mersey Estuary and to a lesser extent on the River Dee. The Isle of Man has a low population and is not heavily developed. The principal towns and their associated harbours (Douglas is the main port) are situated on the five major estuaries. The east and south-west coasts of the island consist of rocky shores and have a rich diversity of flora and fauna. Most of the sandy beaches are on the exposed north-west coast and have a low species diversity.

Colwyn Bay to Kenfig: A feature of this section of coastline is the island of Anglesey which is separated from the mainland by the narrow Menai Straits. The coasts of Anglesey and the Llyn Peninsula to the south are rocky and their limestone habitats, cliffs and heath-covered slopes support important plant and seabird communities. At many points along this coastline there are sand dune systems and salt marshes, often associated with bays and estuaries. On the northern shore of the Bristol Channel several large estuaries and sand dune systems have been encroached on by industrial developments, including a large steelworks. Milford Haven is a sheltered deep-water anchorage with a major oil terminal and refineries. Swansea Bay is bordered by the main urban, industrial and port developments of the area.

Kenfig to Land's End: The central feature of this coast is the Severn Estuary, one of the most extensive estuary systems in Region III. Cardiff and Newport on the south coast of Wales, and Avonmouth on the southern shore of the Severn Estuary, are large industrial centres

and all are major trading ports. As the prevailing winds are from the south-west, the coasts of Devon and Cornwall to the south are far more exposed than those of the Severn Estuary and Bristol Channel. There is limited industrial activity in this region and the hinterlands are used mainly for low-intensity agriculture. The more southerly part of this coast is noted for its sea cliffs, including the headlands of Land's End and Cape Cornwall.

Malin Head to Carlingford Lough: The Malin Sea coast of Northern Ireland, from Lough Foyle to Larne, is thinly populated with only light industries and the hinterlands are devoted largely to pasture-based agriculture. Lough Foyle is an extensive embayment containing a large area of sandy shore (Magilligan strand). To the east there is a remarkable basalt pavement formation known as the Giant's Causeway which attracts half a million visitors annually. There are large sandy beaches that attract tourists. The Bann River catchment, which includes the largest lake (Lough Neagh) in Region III supports a population of approximately 360 000 people. There are major ports at Londonderry (Lough Foyle) and at Larne. Larne, one of the main ports in Northern Ireland (other east coast ports are at Belfast and Warrenpoint), is situated at the entrance to Larne Lough. To the south there are three other major sea loughs (i.e. Belfast, Strangford and Carlingford Loughs). These large inlets are characterised by fine sand as well as extensive areas of intertidal mud and salt marsh. There are sandy beaches on the southern approaches to Belfast Lough and on the Ards Peninsula north of Carlingford Lough. Intertidal rock is most extensive in the south of the region, occasionally associated with coarse shingle banks (e.g. in Strangford Lough). Belfast is the largest town on this coast and the most important industrial centre.

Carlingford Lough to Carnsore Point: Ireland's east coast is less indented than other Irish coasts and is approximately 480 km in length. The hinterlands are among the drier parts of the country, having on average less than 150 days per year with more than 1 mm rainfall. From Carlingford Lough to Howth Head, the shoreline is characterised by softer forms of intertidal substrate and includes extensive linear sandy beaches. With the notable exceptions of Dublin Bay and Wexford Harbour, the coast from Dublin Bay to Carnsore Point is distinguished by an absence of bays and inlets and a transition from mainly harder intertidal substrates in the north to extensive sandy beaches in the south. A notable feature is the long stretch of shingle beach between Killiney and Wicklow. There are several inlets and estuaries of importance to birds, marine life, recreation and shipping. Dublin and Rosslare, the two major ports on the east coast, have developed around the estuaries of the Liffey and Slaney. Other significant inlets are Carlingford Lough at the border with Northern Ireland and, to the south, the estuaries at Rogerstown, Malahide and Baldoyle which have relatively narrow entrances and

large expanses of intertidal substrate. Dublin, Ireland's capital city, occupies a central position on the east coast. The city and surrounding areas support a large population and a wide range of commercial activities. Today, much of the east coast and its hinterland is used intensively for residential, recreational, agricultural and commercial purposes but there are also extensive habitats for flora and fauna. There are regionally important ports at Drogheda and Dundalk and major fishery ports at Skerries, Howth, Arklow and Wexford.

Carnsore Point to Mizen Head: The southern coastline of Ireland is much more rocky and indented than the east coast and approximately 1300 km in length. There are numerous small bays and estuaries and large, navigable estuaries at Cork Harbour and Waterford Harbour. The south coast is moderately sheltered from the prevailing west to south-west winds. The coast to the east has sandy beaches for more than half its length with rocky and muddy substrates comprising about 16% and 13% respectively. Westwards, the intertidal substrates become increasingly rocky with a corresponding reduction in sand and varying amounts of mud. Cork is the largest city on the south coast and a centre of manufacturing and commerce. Cork Harbour is a large natural inlet with a narrow entrance from the sea, providing port facilities for cargo vessels up to 100 000 t. There are important fishery ports at Dunmore East, Duncannon and Kilmore Quay in the vicinity of Waterford Harbour and at Union Hall and Baltimore in County Cork.

Mizen Head to Clew Bay: This coastline is very rocky with a series of large bays and inlets that provide a degree of shelter from the prevailing south-westerly winds and large Atlantic waves that are prominent features of the west coast environment. To the south of the area there is a series of long, narrow inlets (i.e. rias) separated by mountainous peninsulas. These attract large numbers of tourists as does the Galway coast further north. The inlets also support an important mussel cultivation industry. From Tralee Bay to Galway Bay there are stretches of more linear coastline, including some long sandy beaches, although the foreshore remains predominantly rocky with steep cliffs in many areas. North of Galway Bay the shoreline is once more highly indented and characterised by an irregular series of rocky bays with small sandy beaches. The Corrib system, which enters Galway Bay through a short estuary at Galway city, includes two large lakes – Lough Corrib and Lough Mask – which support important salmonid fisheries. The Shannon Estuary extends about 100 km from the tidal limits at the Ardnacrusha hydroelectric power station to the mouth at Loop Head. The Shannon river is 250 km in length and has a catchment area of 11 200 km². A deep-water port is located at Foynes and smaller vessels (6.5 m maximum draft at spring tide) can navigate the upper estuary to Limerick dock. Apart from a few major towns the popula-

tion is thinly dispersed. The main centres of population and commerce are Tralee, Limerick, Ennis and Galway. On the Shannon Estuary, industrial estates at Limerick and Shannon are important centres of manufacturing industry. In addition to the commercial ports at Foynes and Limerick, the only other port handling general cargoes is at Galway. The most important fishery harbours in terms of landed catches are at Castletownbere, Dingle, Valentia and Fenit in County Kerry and Rossaveal on the northern side of Galway Bay.

Clew Bay to Malin Head: Ireland's north-west coast is predominantly rocky but has many large bays with fine sandy beaches. It is also heavily indented and has a number of large promontories exposed to strong westerly winds and some of the largest waves in Region III. There are many small islands, especially in Clew Bay and off the west coast of County Donegal. Prominent features of the north coast are the three large sea inlets of Sheephaven Bay, Mulroy Bay and Lough Swilly which support important mariculture operations. The north-west is one of the more remote and undeveloped regions of the country and this, combined with some notable upland and coastal scenery, makes it a popular destination for tourists. There are important fishery ports at Killybegs, Greencastle, Rathmullan, Burtonport and Downings in County Donegal.

2.3 Geology and sediments

Contemporary seabed sediments across the region are derived from coastal erosion, limited fluvial input and, most importantly, reworking of the glacial sediments. The sediments have been redistributed and fashioned by tidal currents since sea level reached its present position about 5000 years ago. Sediment input into the region since that time has been minimal except for debris derived from shells and other calcareous organisms. Sediment accumulation in the estuaries arises from riverine sources, coastal erosion or offshore sources. Loss of sandy sediment off the shelf into the deeper water of the continental slope has been minimal.

The seabed across the region may be divided into a number of broad types as illustrated in **Figure 2.2**. These results are a simplification of data obtained from the thousands of seabed samples and seismic profiles collected from the region. The distribution of different sediment types is largely a function of the tidal streams; where the tides are strongest, only gravely sediment persists but, where they are weak, mud accumulates. Slight variation in the strengths of the ebb and flood currents lead to a slow movement of sandy sediment across the region. The direction of net sediment transport may be deduced from the asymmetry of sand waves and numerical modelling of the tidal streams.

2.4 Hydrography and climate

Region III extends from oceanic conditions at the shelf break to the west, through the relatively shallow semi-enclosed Irish Sea, to estuarine and fjordic inlets on its eastern boundary. In very general terms the overall water movement is from south to north, with oceanic water from the North Atlantic entering from the south and west of the region and moving northwards through the area, to exit into Region I (Arctic Waters) to the north or, after flowing around the north of Scotland, to enter Region II (the Greater North Sea). There are however, complex intermediate water movements, particularly within the Irish Sea. The detail to which these are understood has developed substantially in recent years through the application of modelling techniques, drifting buoys, continuous current

profilers and towed devices for continuously recording temperature and salinity.

The incoming oceanic water, and the water to the west of Ireland and the Western Isles of Scotland and within the Celtic Sea, is relatively (although not completely) unaffected by human activities. Only that component which flows into the Irish Sea from the south receives much in terms of land-based inputs of contaminants (see also Chapter 4). The numerous offshore islands of the Malin Shelf tend to shelter the Scottish mainland from the extremes of the generally westerly airflow and also tend to segregate the northward flow of water out of the Irish Sea from the oceanic current to the west. Further information on the detail of the water circulation in Region III and the extent to which it is dependent on, or influenced by, the overall climate and weather fluctuations, is provided in the following sections.

Figure 2.2 Major seabed sediment types within Region III.

Source: BGS.



Simplified from the BGS 1:1 million map of seabed sediments around the UK (1987)

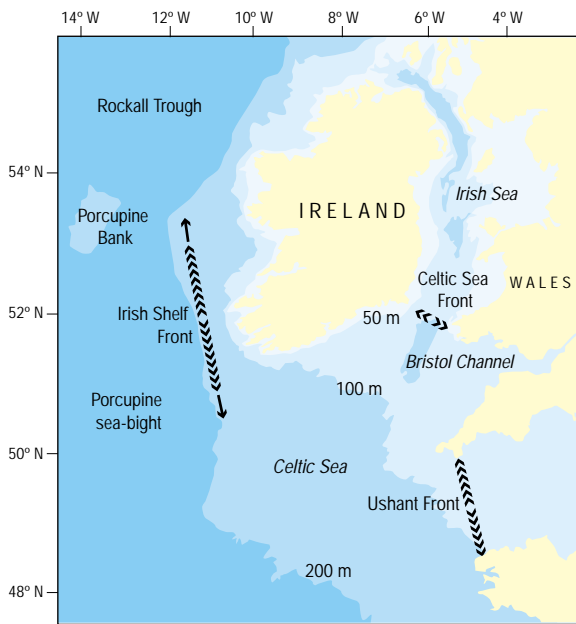
2.5 Water masses

The general pattern of salinity distribution derived from long-term data sets shows that, in winter, near shore salinities to the west of Ireland and eastwards to approximately 8° W, average 35 or greater, indicating the water is mainly of Atlantic origin. In summer the 35 isohaline moves offshore and a band of surface water in the range 34.5 – 35.0 surrounds the Atlantic and Celtic Sea coast of Ireland. Surface salinities increase steadily towards the open ocean reaching approximately 35.5 at the shelf break. Partly due to lack of data, the general pattern of bottom water salinities is more difficult to define, but there is a tendency for Atlantic water to extend somewhat further eastwards at the bottom than at the surface. This results in pronounced vertical salinity gradients, especially in early summer when warmer stratified water overlies the cooler mixed Atlantic water.

On the Malin Shelf off Scotland there are three water masses. The main body originates in the North Atlantic and has a salinity > 35.0. Water flowing north out of the Irish Sea has a salinity that is normally 34.0 – 34.5 and inshore of this lies coastal water with an even lower salinity due to land run-off. These three water masses also show different seasonal variations in temperature; the Atlantic water temperature ranges from 8 to 13 °C, whereas the inshore waters range from 6.5 to 13 °C and in sea lochs the range can be even greater.

In the Malin Sea area haline stratification is relatively weak. However, as in the Irish Sea, stratification due to surface heating develops over much of the Malin Shelf during late spring and summer. In the Atlantic water zone the thermocline is very marked (4 – 5 °C temperature difference) and usually lies at 30 – 50 m. Inshore the temperature difference between surface and bottom waters is less and in the Minch and Sea of the Hebrides

Figure 2.3 Frontal systems of the Celtic Sea and Atlantic seaboard.



the water column may remain mixed even in summer, leading to the development of fronts. Fronts tend to inhibit lateral dispersion and are often marked by along-front currents and a high phytoplankton standing crop. The Islay front, which runs from Tiree to Malin Head, separating the Atlantic water from Irish Sea water and deflecting the latter into the Sea of the Hebrides, is a typical example and has an along-front current of 20 cm/s.

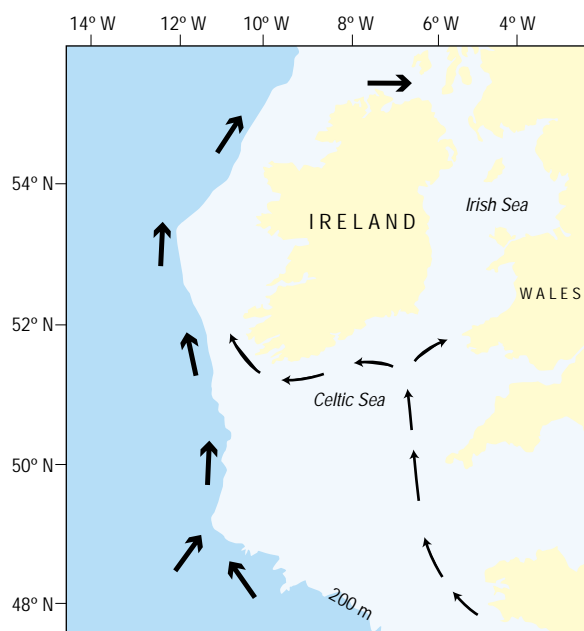
Sea surface temperatures on the shelf, both to the west and south of Ireland, are several degrees warmer in winter than those found in the comparatively shallow Irish Sea, which loses heat more rapidly than the waters west of Ireland and Scotland, that are both deeper and influenced by warmer Atlantic water derived from the North Atlantic Drift. During the summer, bottom temperatures in stratified areas may be 5 – 6 °C cooler than the overlying surface water. Frontal systems tend to develop in late spring at the confluence of mixed and stratified areas, for example the Celtic Sea front to the south of the Irish Sea and the Irish Shelf front to the west of Ireland (Figure 2.3). These break down with the onset of winter cooling and increased wind-induced mixing. Stratification also occurs in the Irish Sea, especially to the west of the Isle of Man where the water is deeper and the tides weaker than to the east of the island. This stratification is due primarily to the strong temperature differences that develop between surface and bottom waters because the tides are not strong enough to cause mixing throughout the water column. The resultant thermocline lies between 20 and 40 m depth depending on the year and breaks down in autumn and rebuilds in spring.

The long inlet of the Bristol Channel between south Wales and the south-west of England peninsula, is exposed to the mainly south-westerly winds from the Atlantic and strong tidal flows (the tidal range being among the largest in the world e.g. 12 m at Avonmouth near Bristol). As a consequence there is intense vertical mixing throughout the estuary east of 5° W. There is substantial freshwater input to the Bristol Channel from the River Severn, accounting for 60% of the total freshwater input at the extreme east of the inlet, and the Welsh rivers to the north account for a further 30%. The consequence is that salinity throughout the area is typically < 35 with a clear north-south gradient. West of about 5° W stratification does occur in summer months with surface waters reaching 17 °C or more and waters below the thermocline remaining < 11 °C.

2.6 Circulation and volume transport

The general pattern of water transport around and within the region is shown in Figure 2.4. On the basis of current measurements it is known there is a persistent north-westerly current, which averages about 6 cm/s and follows the slope edge from the Bay of Biscay to the south-west of Ireland. There is also known to be a weak, variable but persistent flow from the coast of Brittany across the mouth of the Channel. North of the Isles of Scilly part of this flow moves west along the south coast of Ireland with the remainder flowing weakly northwards.

Figure 2.4 General circulation on and around the Irish Shelf. Source: adapted from Pingree and Le Cann (1989).



Evidence from tracer studies suggests the net long-term transport through the Irish Sea occurs at an overall speed typically of 1 – 2 cm/s. However, the day-to-day pattern is much more complex than these statements imply.

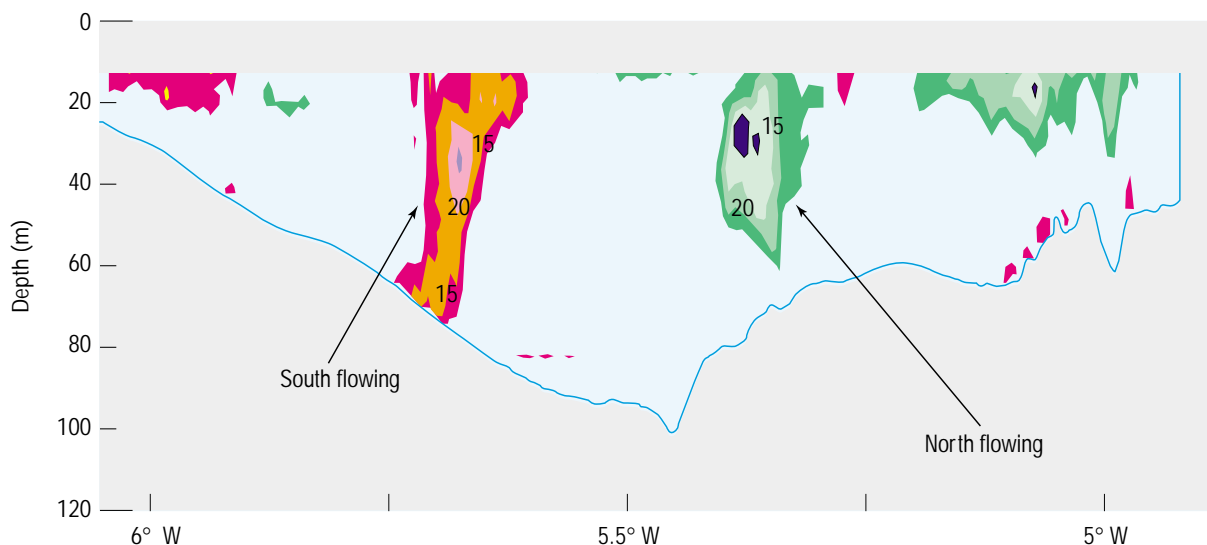
In the centre of the Celtic Sea flow is weak (< 2 cm/s). During summer the Celtic Sea is strongly stratified and a pronounced surface front stretches across St George's Channel. To the south is a deep pool of cold, saline Atlantic water bounded by strong fronts that intersect the seabed. These features drive strong (> 20 cm/s) but narrow (20 km wide) flows, moving water initially eastward across the mouth of the Bristol Channel, into St George's Channel and back into the Celtic Sea. This circulation restricts circulation between the Irish and Celtic Seas during summer. Tidal movement is the most energetic component and the large spatial variation in amplitude of the tidal currents determines many of the processes within the Irish Sea. However, wind-driven currents are important particularly around coasts, especially where the 200 m isobath is close to the coast as it is north-west and south-west of Ireland.

The boundary between the stratified region west of the Isle of Man and the surrounding vertically well-mixed water is marked by surface and bottom fronts. The surface front, extending from Dublin to the Isle of Man, is visible in infra-red satellite images. The bottom fronts drive strong (> 20 cm/s) but narrow (10 km wide) currents in an anticlockwise direction around a dome-shaped pool of colder water (**Figure 2.5**). This gyre tends to retain material in that subregion and means there is a southerly flow along the Irish coast. When the stratification breaks down in the autumn the long-term mean northerly residual

flow resumes until stratification rebuilds the following spring. However, water movements counter to this residual have also been detected in the north-eastern Irish Sea running south-east parallel to the Cumbrian coast and in the North Channel southerly along the Irish coast. These currents are of variable persistence and may be wind-induced. Wind-induced currents are in fact important in Region III and can, during long windy periods, induce flows of up to 50 cm/s throughout the entire water column. The development of such strong wind-induced currents illustrates the limitations of the concept of normal residual flow; there are frequent variations about the norm including complete reversal at times. On average though, water transport is northwards through the North Channel (estimated to be 30 000 – 100 000 m³/s) with the greatest transport being on the eastern (Scottish) side.

Water movements on the Malin Shelf basically follow the same overall residual northerly direction, however the short-term flow is equally variable and strongly influenced by weather systems. Depressions passing north of Great Britain tend to induce a strong northward pulse whereas those passing further south tend to induce weaker southerly currents. Based on dilution of two caesium isotopes it has been estimated that the volume transport to the west and east of the Outer Hebrides is of the order of 20 000 and 90 000 m³/s respectively. Although most of the water passes into the Sea of the Hebrides, a small proportion is recirculated around Barra Head to the west as evidenced by the path taken by drifting buoys. This recirculation is thought to be forced by intrusion of deep Atlantic water which forms a cyclonic surface circulation similar to the deep water 'domes' of cold water found elsewhere.

Figure 2.5 Seasonal subsurface anticlockwise currents (cm/s) in the Irish Sea to the west of the Isle of Man in July 1994. Source: CEFAS.



Based on transport models and radionuclide distributions, water moving up the west coast of Scotland typically takes 4.5 to 6 months to pass from the North Channel to the north of Scotland. Similarly, the overall flushing period for the Irish Sea is estimated to be of the order of 1 to 2 yr. The Bristol Channel flushing time is estimated to be between 150 and 300 days. Such figures need to be treated with considerable caution, for example it is estimated that 20 – 30% of the water from the Irish Sea was removed by a single storm event in February 1994.

The numerous sea lochs (fjordic estuaries) on the western coast and islands of Scotland are more responsive to changes in temperature and rainfall than the adjacent coastal water. Most west coast rivers discharge into these lochs; the resultant surface layers exhibit wide-ranging temperatures and reduced salinity. Shallow sills restrict exchange with coastal water. Water renewal usually occurs every few weeks but in Loch Etive it takes on average fifteen months. Anoxic conditions are rarely reported in sea lochs, although very low oxygen concentrations have been observed in the deep water of Loch Ailort. Circulation is typically estuarine with seaward flowing currents on the surface and a deeper return flow. Over the sills tidal currents can reach speeds of around 1 m/s. Many sea lochs have internal tides that contribute to mixing between deep and surface layers.

The Firth of Clyde is a wide fjord containing a deep basin separated from the North Channel by a sill. Thermal stratification remains strong throughout the summer. Haline stratification is variable but persists throughout the year. The deep waters of the Clyde are replaced during winter. A front exists above the sill throughout the year, separating tidally mixed water in the North Channel from the stratified Clyde. Depth-averaged currents across the sill are about 20 – 30 cm/s.

Numerical models offer a holistic view of large-scale spatial and temporal variability not possible with limited observations. Since the 1970s two-dimensional models of the region have been used primarily for tide and storm surge prediction and for simulating the dispersion of contaminants. However, the resolution of these models was hampered by computing power until the late 1980s when increased horizontal resolution three-dimensional circulation models were developed. These models include atmospheric forcing and tides, allowing the determination of density fields and associated flows at a resolution of up to 1 km on the regional scale. Such models now replicate accurately tidal dynamics and the principal response of the Irish Sea to wind forcing. Provided they are of sufficiently high resolution these models can be developed further to examine specific issues such as sediment and contaminant transport pathways and the dynamics of fisheries recruitment on more local scales.

Thus, for example, when good quality tidal models are combined with models of the seasonal cycle of surface

heating, a detailed picture of the seasonal evolution of stratification is obtained. This approach lends itself to the simulation and understanding of biological production and transport pathways. In this latter respect, only when this approach was adopted, allied to observations, was the existence and significance of the western Irish Sea circulation understood. Three-dimensional, fully baroclinic models are being developed for the Malin Shelf and should similarly assist the understanding of processes such as the surface recirculation around Barra Head.

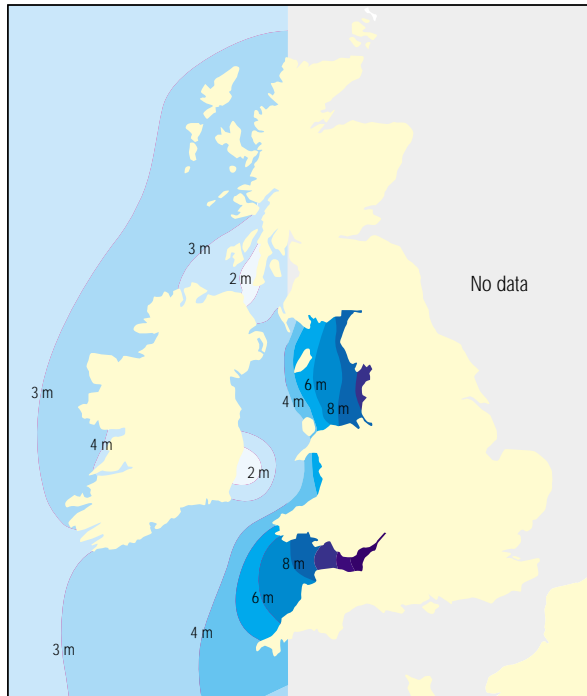
2.7 Waves, tides and storm surges

Surface waves depend upon the duration and fetch of the wind. The coastline of the west of Ireland and the Western Isles of Scotland are exposed to a vigorous wave climate. There is a general tendency for waves to be smaller south of approximately 52° 5' N and east of 11° 5' W as swell waves from the Atlantic diminish due to the effects of bottom friction. Within the Irish Sea the waves tend to be locally generated and are of fairly short period (50-yr mean values of the order of 10 s within the Irish Sea and 15 s at its outer entrances). They are, however, relatively steep with 50-yr significant wave heights ranging from 8 m within the Irish Sea to 12 m at its entrances. Very similar figures are reported for the Bristol Channel; 12 m at its mouth and 8 m east of the Gower Peninsula. The effect of waves within the shallow eastern Irish Sea, and inner Bristol Channel in particular, can thus be significant during storms, with marked sediment resuspension. There is some evidence that, in recent years, mean wave heights in the North Atlantic have been increasing by an average of 1 – 2% per year. It is however, unclear whether this is just natural variability as, although storm frequency appears to be showing an upward trend, wind strength does not appear to be increasing.

Figure 2.6 shows the spring tidal ranges experienced throughout Region III. In the open Atlantic tidal waves are generally small but they increase as they move eastwards across the shelf and are further enhanced by the funnelling effect of bays and estuaries. Thus, for example, halfway up the Shannon Estuary on Ireland's west coast the average tide is 4.5 m but at the head of the estuary it is almost 1 m higher.

The tidal waves in the Irish Sea are propagated from both north and south and meet to the south-west of the Isle of Man causing this area (an amphidromic point) to have very weak tidal currents (< 35 cm/s). There is another amphidromic point south of Islay on the Malin Shelf. However, around Anglesey and the Mull of Galloway, tides are much stronger and peak flows exceed 120 cm/s. It should be noted that the tidal currents are averages for the areas in question and local sudden changes in depth or coastal topography, for example

Figure 2.6 Spring tidal ranges in Region III. Source: adapted from ECOPRO (1996); Lee and Ramster (1981).



around a headland, may generate much higher velocities. The tidal currents in the Bristol Channel generally exceed 150 cm/s at spring tides at which times a tidal bore forms in the Severn Estuary which can be up to 2 m high on occasions. Off the west coast of Ireland tidal currents are generally weaker with maximum speeds generally < 50 cm/s. The turbulent kinetic energy generated by the high tidal currents in the Bristol Channel maintains high levels of particulate material in suspension. However, the asymmetrical tidal current also means that there is a general westward transport of suspended material with a bed load parting region between Barry and Bridgwater, which lie on opposite sides of the Bristol Channel.

Tidal ranges on the Malin Shelf are from 0.5 m on a neap tide (1 m on a spring tide) in the Sound of Jura (just south of the amphidromic point south of Islay) to 1.6 m on a neap tide (4.5 m on a spring tide) east of the Isle of Skye. Further offshore and north of Skye the tidal range is reduced. Within the Irish Sea maximum tidal ranges occur on the Lancashire and Cumbrian coasts where the mean spring tides have a range of 8 m, contrasting with Carnsore Point on the south-east Irish coast where the range is only 1.75 m. The funnelling effect of the Bristol Channel, together with overall dimensions which cause its natural period to be close to the 12.5 hr tidal period, means the area has one of the largest tidal ranges in the world; for example at Avonmouth it exceeds 12 m on spring tides.

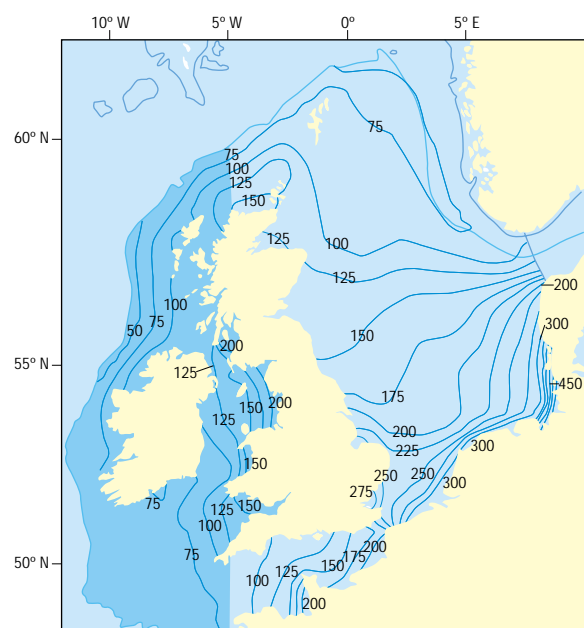
Storm surges occur when water is forced up against

the coast through the combined action of wind and low atmospheric pressure. The largest surges are generally associated with storms tracking eastwards between Inverness and the Shetlands. Maximum surge levels within Region III are predicted to occur in the north-eastern Irish Sea and may reach 2 m above normal (Figure 2.7). Surge levels of between 0.75 and 2 m are predicted for the Irish Sea coast and across St George's Channel. These predictions are borne out by experience. In February 1990 the storm surge throughout the Irish Sea was of the order of 0.5 – 1 m but exceeded 2 m on the North Wales coast causing serious flooding. Only two months earlier a strong south-westerly wind and an atmospheric pressure of 941 mb caused a surge in Cork Harbour on the south coast of Ireland of 0.56 m. The low-lying coasts on the southern side of the Bristol Channel are particularly vulnerable due to the very high tidal range. Estimates of extreme sea level suggest a 1 in 50 year maximum level of 8.69 m at Avonmouth.

2.8 Transport of solids

The sand transport pattern is complex with a zone of divergence across the Irish Sea west of Anglesey and in the North Channel, and a dominant westward trend out of the Bristol Channel and across the Celtic and Malin Seas. The sand-grade sediment moves along near the seabed while the mud-grade sediment moves largely in suspension.

Figure 2.7 Fifty-year average storm surge elevations (cm) for sea areas surrounding the British Isles. Source: Flather (1987).



Thus they may have different transport pathways. Where the seabed is rock and gravel, tidal and storm-wave currents have a limited effect on the seabed, however the abundance of bedforms such as sand waves across sandier areas indicates the transport of large volumes of sand. Earlier sections of this chapter refer to the influence of wind on currents. In the shallower areas of Region III wind-generated waves cause the resuspension of seabed sediments during storm events. In the Bristol Channel, and to a lesser extent other major estuaries such as the Shannon and Mersey, high levels of particulates remain in suspension due to the strong tidal currents.

2.9 Meteorology

Within Region III calm conditions (wind speeds < 0.2 m/s) are likely to occur less than about 2% of the time. The strongest winds come from the west and south, with a tendency for the strongest winds to be experienced to the north and west of the region. Based on 30-yr records, there is no evidence of any trend in wind patterns or their strength, although there are indications of an increase in the frequency and severity of storms. The rainfall in the coastal regions bordering Region III is strongly influenced by the topography, with west facing coasts generally experiencing the heavier rainfall, especially where there are mountains close to the coast. In the Malin Sea area some mountains in Scotland average more than 300 mm of rain per month, whereas less hilly regions receive only about one third of that amount. The strong winds and high rainfall experienced in these west coast regions, together with their generally lower temperatures, severely restricts the human activities that can be practised in these areas.

Average sea surface temperatures to the west and south of Ireland range from 8 – 10 °C in February or March, to 14 – 17 °C in August. The winter temperatures are several degrees warmer than those experienced in the Irish Sea. This is a consequence of greater heat loss in the coastal waters compared to the deeper Atlantic waters influenced by the North Atlantic Drift. However in summer shallower parts of the Irish Sea warm more quickly in response to the warmer summer air temperatures. Regions that stratify in summer can be lower in temperature than normal after a hot summer and conversely warmer than normal following a cool summer. This is because in a hot summer wind strengths are generally lower; this in turn limits the depth of the surface mixed layer so that less heat is stored, whereas in a cool windy summer the thermocline is driven deeper and the mean temperature of the water column as a whole is higher.

The temperature of the water column is a major factor in determining the time of spawning of some species of fish and crustacean. In addition, the timing of formation of the thermocline has implications for the timing of the

spring phytoplankton bloom and thus, overall productivity. Accordingly, temperature differences on a year by year basis and any long-term trend have implications for both species composition and recruitment.

2.10 Climate variability

Long-term fluctuations in surface heat exchange, wind-field, freshwater input and exchanges with the outer shelf can be expected to play a role in the inter-annual and decadal variability of physical processes. Unfortunately, continuous time series of hydrographic parameters over decades do not exist for Region III. However, the limited size and rapid flushing time of the Irish Sea make it likely that hydrographic changes influenced by climate will occur rapidly. Whilst the effect of global warming is notoriously difficult to detect in coastal waters, it is possible that decadal variability in climate over the North Atlantic might affect the region's hydrography. Broadly, the atmospheric pressure distribution over the North Atlantic in winter can be characterised by two alternate states: the first, an intense Icelandic low and a strong Azores ridge to the south, and the second, a weak Icelandic low and Azores high. The oscillation between these two characteristic patterns is the dominant mode of atmospheric behaviour over the North Atlantic and is termed the North Atlantic Oscillation (NAO). The first state, termed a positive index, is associated with strong mid-latitude westerly winds, higher frequency Atlantic storms and increased wave height in the North-east Atlantic when compared to the second state, a negative index.

A direct link between the NAO and the hydrography and climate of the Irish Sea has not been established; however it is reasonable to expect a degree of correlation. For example, a positive index results in a higher frequency of Atlantic storms, the centres of which track to the north of Great Britain, favouring more frequent resuspension of sediment in shallow coastal environments through increased wave activity. Additionally, depressions passing to the north of the Irish Sea promote northerly and westerly winds over the region which are likely to increase the incidence of storm surges in the eastern Irish Sea.

As the regions of significant freshwater influence are limited to Liverpool Bay and the Bristol Channel, and to a lesser extent the Shannon Estuary and the Irish east coast from Dundalk Bay southwards, the impact of significant variability in rainfall is likely to be localised. In Liverpool Bay, exceptionally low freshwater input may mean that the characteristic near-bed inflow and surface outflow is greatly diminished. Alternatively, periods of prolonged flow are likely to enhance the flushing of the region. It has been suggested that increased freshwater input on the western side of the Irish Sea is likely to promote greater

southward flow and, dependent on timing, may act to promote the normal formation of seasonal stratification.

Changes in rainfall patterns, increased temperature or the increased frequency of westward-tracking storms could all have impacts on the living resources of the region. If, as predicted, global warming continues to occur, there will be attendant increases in sea level due to thermal expansion of the water column and melting of the polar ice caps. This could result in increases in sea level of 15 – 95 cm within the next century. As the southern regions generally have lower coastal profiles they are more likely to be subject to flooding and coastal erosion. Thus in Ireland it is estimated that up to 176 000 ha of land could be at risk, with a real possibility that major disruption could be caused in Belfast, Dublin, Cork and Galway. Areas particularly vulnerable to sea level rise include the Shannon Estuary and the coasts of Cork, Kerry, Clare, Galway, Mayo and Donegal, together with areas along the Bristol Channel, the north Wales coast and around the embayments of the north-eastern Irish Sea such as Morecambe Bay. Many of these areas are currently protected by engineered coastal defences such as sea walls, but these have a relatively short structural life even under stable conditions and alternative approaches to coastal protection, or even the abandonment of areas most likely to be affected, will be necessary (see also Section 3.7).

2.11 Focus areas

It is clear that physical geography and hydrography are key factors in determining the actual and potential effects of human activities on marine and coastal ecosystems. For example, some estuaries and areas with restricted

water circulation are under pressure as a result of high population density, industrial and/or port-related activities. Examples are the Severn Estuary and Mersey Estuary/Liverpool Bay area on the west coasts of Wales and England, the Clyde Estuary on the south-west coast of Scotland, Belfast Lough in Northern Ireland, and the inner parts of Dublin Bay and Cork Harbour in Ireland.

In certain areas such as Liverpool Bay, weak circulation allows relatively high rates of deposition and accumulations of fine sediment that tend to retain contaminants. Such conditions may also occur offshore due to the presence of seasonal gyres. A notable example is the mud patch to the west of the Isle of Man that is also a prime habitat for the commercially valuable Dublin Bay prawn, *Nephrops norvegicus*. Monitoring trends in contamination within these depositional areas can provide a useful indication of the extent of contamination over much larger areas.

Most of the west-facing coasts of Ireland and Scotland and the Western Isles off Scotland are important in the contexts of fisheries, mariculture, tourism and wildlife conservation and would be vulnerable to the effects of oil or chemical spills should accidents occur to passing ships. Traffic separation schemes are intended to minimise the risk of collisions and, except in bad weather, ships are expected to avoid inshore routes. Although organic wastes from mariculture have caused localised impacts in some sheltered inlets, improved management has led to a reduction of such impacts as well as the number of areas affected. A less manageable problem is that caused by seasonal upwellings of nutrient-rich oceanic water that can stimulate the growth of toxin-producing algae. Where this coincides with valuable mariculture sites (e.g. south-west Ireland), temporary closures of shellfisheries are sometimes necessary. In Ireland, this is an important focus for research.