5 CELTIC SEA AND WEST OF SCOTLAND

5.1 Ecosystem overview

5.1.1 Ecosystem components

Bottom topography substrate and circulation

The 'Celtic Seas' comprise the shelf area west of Scotland (ICES Subarea VIa), the Irish Sea (VIIa), west of Ireland (VIIb), as well as the Celtic Sea proper (VIIf-k) and western Channel (VIIe). Throughout this ecoregion the continental shelf is of variable width. The Celtic Sea south of Ireland is an extended shelf within which most of the area is shallower than 100 m. It is limited to the west by the slope of the Porcupine seabight and the Goban Spur. To the west of Ireland, the Porcupine Bank forms a large extension of the shelf limited to the west by the Rockall Trough. The transition between the Porcupine Bank and the trough is a steep and rocky slope along which reefs of deep-water corals occur. Further north to West of Scotland the slope of the Rockall Trough is closer to the coast line, particularly off NW Ireland, and the Hebrides. West of the shelf break is the Rockall Plateau with depths of less than 200 m. The shelf area itself contains mixed substrates, generally with soft sediments (sand and mud) in the west and tending to rockier pinnacle areas to the east. The Irish Sea is shallow (less than 100 m deep in most places) and largely sheltered from the winds and currents of the North Atlantic. The English Channel is a shallow (40–100 m) part of the continental shelf. Its hydrology is marked by a west to east general circulation disrupted by strong tidal current.

To the west of the region there are several important seamounts, notably the Rosemary Bank, the Anton Dohrn seamount, and the Hebrides, which have soft sediments on top and rocky slopes.

Water circulation on the shelf is strongly influenced by the poleward flowing 'slope current'. This persists throughout the year north of Porcupine Bank, but is stronger in the summer. South of the bank, the current breaks down in the summer, when flow patterns become complex. Over the Porcupine Bank and the Rockall plateau, domes of cold water are associated with retentive circulation. On the shelf is also a weaker current flowing north from Brittany across the mouth of the channel (OSPAR, 2000; Young *et al.*, 2004). Thermal stratification and tidal mixing generates the Irish coastal current which runs westwards in the Celtic Sea and northwards along the west coast of Ireland (Fernand *et al.*, 2006). In the Irish Sea, an inshore coastal current carries water from the Celtic Sea and St. Georges's Channel northwards through the North Channel, mixing with water from the outer Clyde.

The main oceanographic front in the NE Atlantic region is the Irish Shelf Front that occurs to the south and west of Ireland (at ca. 11°W), and exists all year-round. This front marks the boundary between waters of the shelf (often mixed vertically by the tide) and offshore North Atlantic waters. The turbulence caused by the front introduces nutrients from deeper water to the surface where they promote the growth of phytoplankton, especially diatoms in spring, but also dinoflagellates especially where there is pronounced stratification. These are in turn fed on by cohorts of zooplankton and associated with these aggregations of fish (Reid *et al.*, 2001).

On the shelf, tidal mixing and thermo/saline fronts occur at several locations immediately to the west of Britain, including the Ushant Front in the English Channel, the Celtic Sea front at the southern entrance to the Irish Sea, and the Islay Front between Islay and the coast of Northern Ireland. The Islay Front persists throughout the winter, due to stratification of water masses of different salinity. Similarly, where tides are moderate, uneven bottom topography can have a considerable mixing effect, for example in the seas around the Hebrides.

Physical and chemical oceanography

Temperature/salinity

The ICES Annual Ocean Climate Status Summary (IAOCSS) provides long-term time-series for temperature and salinity anomalies from the Rockall Trough situated west of Britain and Ireland dating back to 1975. Shorter data series are available for the western Irish shelf since 1999 (ICES, 2007).

The Rockall Trough is an important pathway by which warmer North Atlantic surface waters reach the Norwegian Sea, where they are converted into cold dense overflow water as part of the thermohaline circulation in the North Atlantic. In 2006, the warm and saline conditions persisted in the upper ocean of the Rockall Trough, though salinity has been decreasing since a peak in 2003 (Figure 5.1.1). The notable decrease in mean salinity in 2006 was caused by the presence of fresher water between the Anton Dohrn Seamount (11°W) and the Rockall Bank (13°W); however, the shelf edge current (at 9°W) had persistently high salinities. Temperatures once again reached record levels, though most of the additional warming since 2005 was confined to the upper 400 m. Upper ocean temperatures (0–800 m) were 0.8°C and salinity 0.04, above the long-term mean (1975–2000).

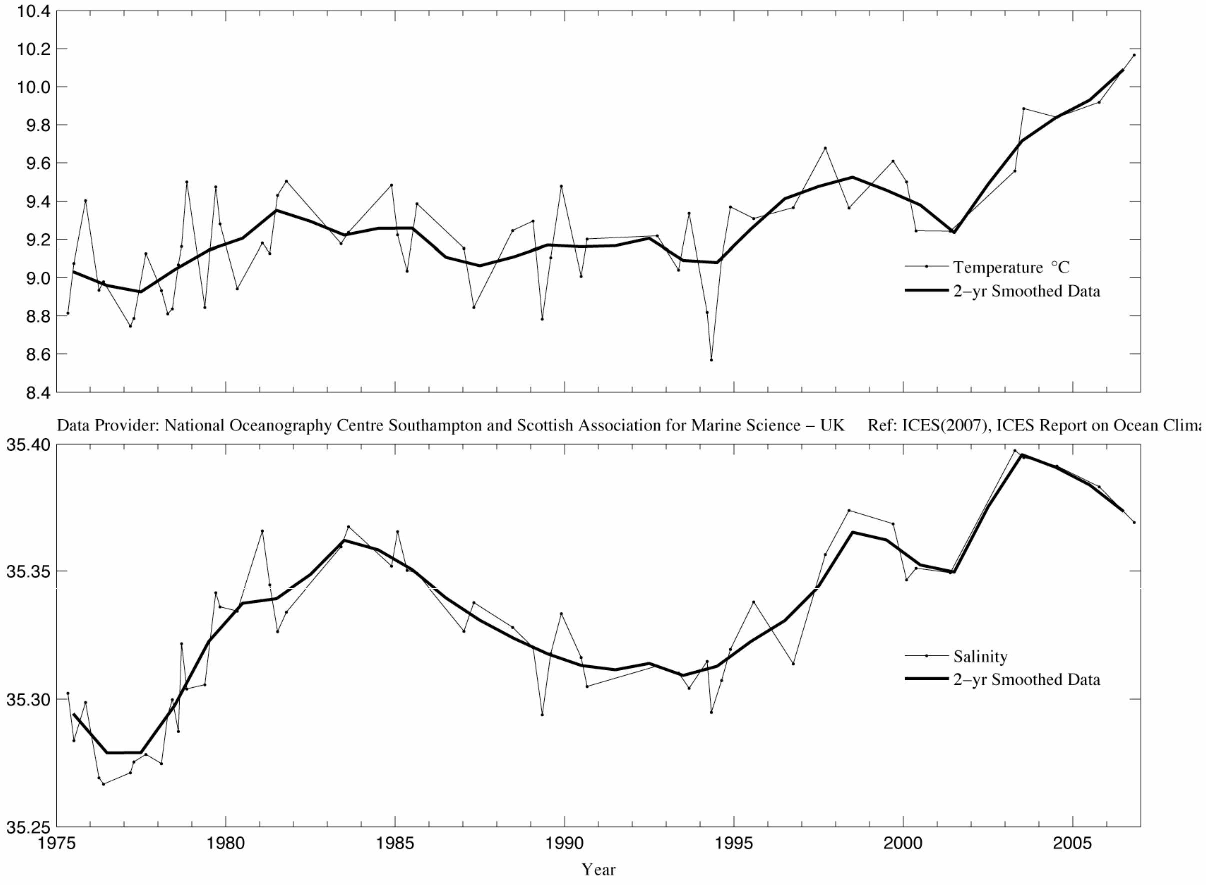

Figure 5.1.1 Rockall Trough temperature and salinity anomalies for the upper ocean (0–800 m) of the northern Rockall Trough. Average across section, seasonal cycle removed.

Summer CTD measurements made along a section at 53°North on the western Irish shelf since 1999 show warmer conditions in 2003 and 2004, broadly consistent with other regions of the NW European shelf while cooler conditions were observed in 2001 and 2002. Salinity also exhibits strong interannual variability along this section, depending on the timing and magnitude of discharges both locally from Irish rivers and from rivers to the south of the section in the UK and France.

Sea surface temperatures measured in coastal stations northwest of Ireland since the 1960s show a trend of sustained positive temperature anomalies from 1990 (Nolan and Lyons, 2006).

Inshore waters off the west of Scotland have also continued to warm, consistent with open-ocean conditions. At Millport, where monitoring has been conducted since 1953, gradual warming is apparent, and the more rapid warming that has taken place since the mid-1990s continued until the time of the last reported data in 2003 (FRS, 2005). Similarly, inshore temperature data from Wylfa Power Station and Amlwch in North Wales showed a pattern of warming from 1967 onwards, as did temperatures at Port Erin in the Isle of Man (Joyce, 2006, www.cefas.co.uk/data/seatempandsal/).

Several temperature time-series, including fortnightly records from a fixed station off the SW coast of the Isle of Man (the Cypris station), a more recent shorter series from a mooring in the western Irish Sea (Gowen, AFBI, Belfast), and two series of combined satellite and ship-recorded data compiled by the Climate Diagnostics Center, National Oceanographic and Atmospheric Administration of the US Department of Commerce (Figure 5.1.2) indicate a general warming trend in the Irish Sea since 1960, with particularly high temperatures in 1998 (ICES, 2006).

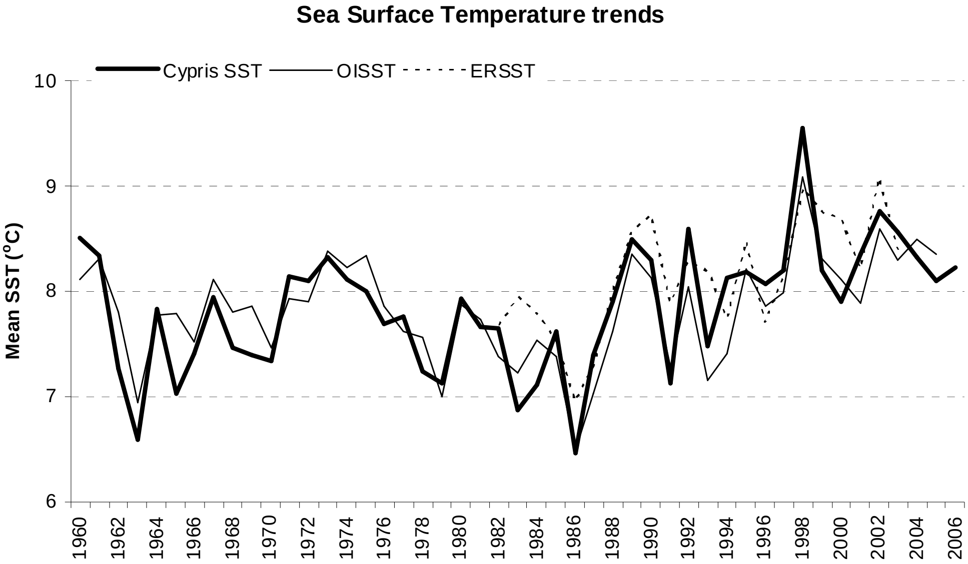

Figure 5.1.2 Sea surface temperature in the Irish Sea from 1960 to 2006 (ICES, 2006b).

High-intensity, near 'real-time' temperature (and in some cases salinity) data are available from monitoring buoys in the Irish Sea (Liverpool Bay, Aberporth, M2), the Bristol Channel/Celtic Sea (M5, Pembroke, Scarweather) and west of Ireland (M1, M3, M4, M6, K2, K4), operated by the Marine Institute (Ireland), CEFAS (UK), and the UK Met. Office (see www.cefas.co.uk/WaveNet/default.htm). Scottish monitoring stations exist at Loch Maddy (North Uist), Mallaig, and Loch Ewe (www.frs-scotland.gov.uk).

The North Atlantic Oscillation index (NAO) is a measure of the difference in normalized sea level pressure between Iceland and the subtropical eastern North Atlantic. When the winter NAO index is positive, this coincides with colder and drier conditions over the western North Atlantic and warmer, wetter conditions in the eastern North Atlantic. During a negative NAO, a weakening of the Icelandic low and Azores high decreases the pressure gradient across the North Atlantic and tends to reverse the effect. The winter NAO experienced a strong negative phase in the 1960s, becoming more positive in the 1980s and early 1990s. It remained mainly negative from 1996 to 2004, but became positive in 2005 (6.7 mbar).

Input of fresh water

Several rivers discharge fresh water into the ecoregion and influence the circulation patterns; these are notably the River Loire, the Severn, and the Irish rivers Lee and Blackwater in the Celtic Sea (Figure 5.1.3). To the west of Ireland, fresh water discharges from Irish rivers (e.g. Shannon and Corrib) and those further afield (e.g. Loire, Severn) interact with Eastern North Atlantic Water. River inputs into the Irish Sea and the Malin Sea north of Ireland are locally important in reducing salinity in these areas. Because of the complex fjordic nature of the western coast of Scotland there is also a substantial fresh-water input from the numerous sea-lochs, notably the Firth of Lorne sealoch system (Nolan and Lyons, 2006).

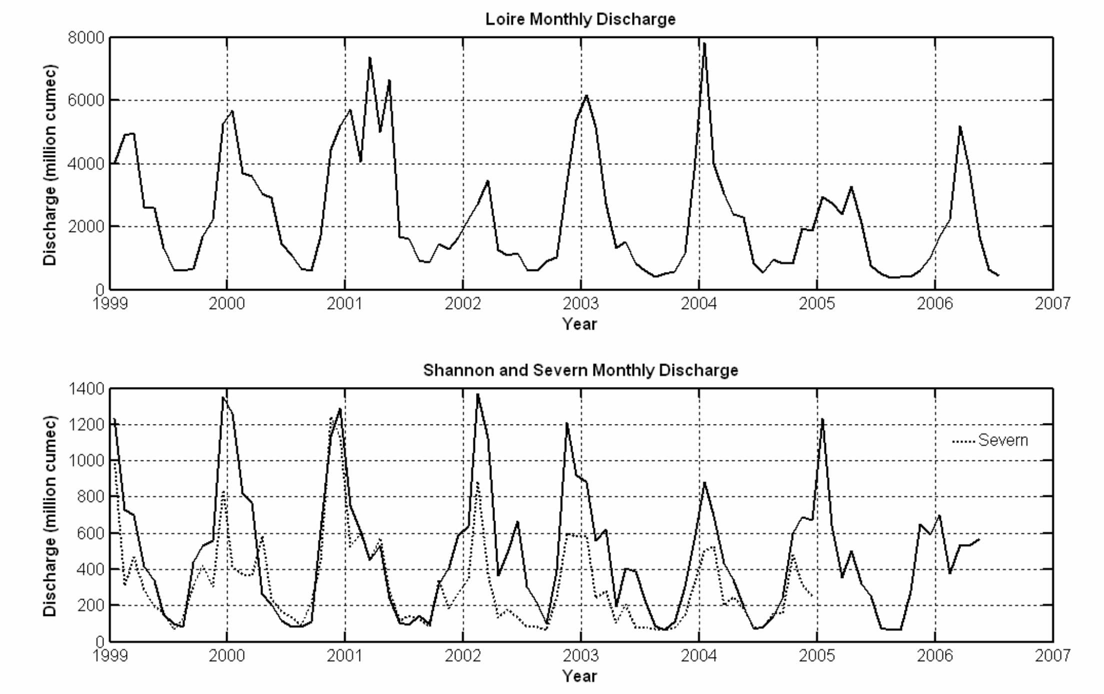

Figure 5.1.3 Discharges from rivers affecting the western Irish Shelf: the river Loire (upper panel) and rivers Shannon and Severn (lower panel). Note different scales on Y-axes.

Broad-scale climate and oceanographic features

See general text on this topic in the separate section on the NE Atlantic (Section 2.9).

Phytoplankton

For most of the Celtic Seas ecoregion productivity is reasonably strong on the shelf but drops rapidly west of the shelf break. Based on CPR greenness records for this area the spring bloom occurs around April and collapses by October, although in recent years it has continued into December. CPR data also suggest that there has been a steady increase in phytoplankton colour index across the whole area over at least the past 20 years. Phytoplankton productivity and taxonomic composition in the Celtic Sea has been shown to depend on water column structure. Diatoms dominate well-mixed areas with high nutrient content and display high rates of productivity, while dinoflagellates and microflagellates are found in stratified waters exhibiting lower rates of productivity (Raine *et al*., 2002). Certain oceanographic conditions can lead to the formation of toxic algal blooms around Irish coasts, with the highest occurrence noted along the southwest of Ireland. Large harmful algal blooms recorded in 2005 were associated with the dinoflagellate *Karenia mikimotoi* and caused mortalities to benthic and pelagic marine organisms at a scale that has not previously been observed (Silke *et al.*, 2005).

Zooplankton

As is true of the adjacent North Sea, the overall abundance of zooplankton in this region has declined in recent years. CPR areas C5, D5, and E5 all show substantial drops in *Calanus* abundance and these are now below the long-term mean. *Calanus finmarchicus* is known to overwinter in the Faroe-Shetland channel and the abundance of these is known to have been reduced in recent years. Distribution of this species in deep waters further south is unknown. More detailed information should be available from the CPR programme, but this is not available at present.

Zooplankton monitoring data are available from one station (“L4”) in the English Channel. This station is influenced by seasonally stratified waters and is maintained by Plymouth Marine Laboratory (ICES, 2006a). Whether or not changes in the zooplankton community evident at this site are representative of changes and trends in the wider “Celtic Seas” remains uncertain, further analyses of CPR data or additional information from static sampling stations (e.g. Nash and Geffen, 2004) are urgently needed to clarify the situation.

The ten most abundant zooplankton taxa at “L4” have been ranked according to their annual mean proportion of the total zooplankton (Table 5.1.1). In 2005, major changes in the zooplankton composition were reported. Not only has the rank order of the top ten species changed, but new groups, Echinoderm larvae, *Noctiluca scintillans*, Siphonophores, and *C. helgolandicus* appear in the dominant species for the first time, contributing 4.6% to 3% of the total zooplankton abundance respectively. In addition, *Ps. elongatus*, which was the most abundant species during the period 1988–2004 when it contributed nearly 12% of the total zooplankton abundance, represented only 2.3% of the zooplankton community in 2005. *Ps. elongatus* abundance in 2005 is the lowest abundance observed over the whole time-series (53 ind. m^{-3}). Peaks of high zooplankton abundance and chlorophyll *a* concentration are regularly observed in spring and late summer/beginning of autumn, the latter resulting from intense summer dinoflagellate blooms in some years. Zooplankton at L4 shows two decreasing trends from 1988 to 1995 and from 2001 to 2005. This is mainly the result of relatively low abundances of the spring species *Paracalanus*, *Pseudocalanus*, and *A. clausi*. Small copepods like *Oncaea*, *Oithona*, and *Corycaeus* contribute greatly to the total zooplankton population.

Table 5.1.1 Percentages and averages of the top taxa at Plymouth "L4" station during the sampling period 1988–2005 time-series and in 2005.

RANK	TAXA	% TOTAL ZOOPLANKTON 1988–2004	% TOTAL ZOOPLANKTON 2005	YEARLY AVERAGE 1998–2004 (N/M^3)	2005 AVERAGE (N/M^3)
1	*Pseudocalanus*	11.74	2.32	380	54
2	*Oithona*	11.30	6.23	366	144
3	*Oncaea*	11.11	7.69	360	178
4	*Paracalanus*	9.53	4.23	309	98
5	*Temora*	9.19	8.52	298	198
6	Cirripeda nauplii	8.69	7.93	281	184
7	*Acartia clausi*	6.18	2.74	200	64
8	*Evane*	5.85	2.25	190	52
9	*Appendicularia*	2.59	1.22	84	28
10	*Corycaeus*	2.25	5.72	73	133
Total		78.43	48.90	2540.62	1133.30
N/m^3				3239.60	2320.40

Benthos, larger invertebrates (cephalopods, crustaceans etc), biogenic habitats

The major commercial invertebrate species in the Celtic Seas ecoregion is Norway lobster (*Nephrops norvegicus*). It is targeted by trawl fisheries on the continental shelf west of Scotland, on the Rockall plateau, and both south and west of Ireland. Cuttlefish (*Sepia officinalis*) is also exploited in the Celtic Sea. Major fisheries dredging for scallops and some smaller bivalves exist in the western Channel, Irish Sea, and west of Scotland. Pot fisheries exploit lobster *Homarus gamarus* and brown crab *Cancer pagurus* in the waters around the Channel Islands (French landing about 150 t $year^{-1}$), and west of Scotland. In addition to major aquaculture activity for oysters and mussels, some beds of wild oysters and buried bivalves such as cockles *Cardium edule* are exploited by professional and recreational fisheries (for example in Morecombe Bay).

The most abundant cephalopods species in the Celtic Sea and west of Ireland are *Loligo forbesi* and *Illex coindetii* which are mainly found close to the shelf break, while *Alloteuthis subulata* is a common species found close to shore in water depths of less than 75 m (Lordan, 2001).

Ellis *et al.* (2000) provided a review of benthic community structure in the Irish Sea and described six distinct assemblages. Plaice and dab dominated on fine substrates in inshore waters, whereas sea urchins and sun-stars dominated on the coarser substrates further offshore. Thickback sole *Microchirus variegates* and hermit crabs were typical of the transitional zone, while Norway lobster and witch (*Glyptocephalus cynoglossus*) dominated on the muddy sediments in the central Irish Sea. Beds of *Alcyonium digitatum* (Dead man's finger) occurred on coarse substrates throughout the study area, whereas common spider crabs were only dominant in the Bristol Channel (*Maja* assemblage). The common starfish (*Asterias rubens*) was an important component of all assemblages and the distribution of these assemblages was primarily correlated with depth, temperature, and substrate type. Kaiser *et al.* (2004) added a distinct sandbank type habitat off the Welsh coast, typified by low species diversity and shared indicator species such as the weever fish *Echiichthys vipera*, the shrimp *Philocheras trispinosus*, and the hermit crab *Pagurus bernhardus*.

Over 340 species of invertebrate and fish were captured in a survey of the epibenthos in ICES Areas VIIf-h (Ellis *et al.*, 2002), the most ubiquitous species being the hermit crab *Pagurus prideaux* and the spotted dragonet *Callionymus maculatus*, both of which are major prey items for commercial fish (Pinnegar *et al*., 2003). Two epibenthic assemblages predominate in the Celtic Sea. The first is dominated by the anemone *Actinauge richardi* (41.8% of the faunal biomass) and occurs along the shelf edge and slope in waters 132–350 m deep. The second assemblage is more widely distributed on the continental shelf (depth range: 66–232 m) and *P. prideaux* dominates along with other mobile invertebrates (shrimps and echinoderms), although there are some spatial differences in assemblage structure and relative abundance.

Rees *et al*. (1999) provided a comparison of benthic biodiversity in the North Sea, English Channel, and the Celtic and Irish Seas. Similar infaunal assemblages were encountered on both the eastern and western UK coasts in comparable environmental conditions. Grab stations in the easternmost part of the English Channel, southern North Sea, and within the Bristol Channel, supported very sparse infauna communities associated with sandy sediments. The highest diversities were generally encountered off the NE and SW English coast. Densities were also relatively high in coastal waters off Morecambe Bay, NW England.

Heath (2005) used the abundance of benthic invertebrate larvae in CPR (continuous-plankton-recorder) data, to establish trends in benthic production for the ‘Celtic Seas’ ecoregion. Based on these data the author reported an increasing long-term trend in benthic production (by 0.8 g C m^2 y^{-1}) between 1973 and 1999.

Biogenic reefs of horse mussels *Modiolus modiolus*, maerl, and Serpulid worms occur in specific locations (Irish Sea, West coast of Scotland). The latter support benthos of conservation interest, such as sea fans and structurally complex bryozoans. Offshore areas on the shelf slope support reefs of deep-water corals such as *Lophelia pertusa.*

Fish community

The northern part of this ecoregion (Irish Sea, West of Ireland, and western Scotland) has important commercial fisheries for cod, haddock, whiting, and a number of flatfish species. Hake *Merluccius merluccius* and anglerfish *Lophius* spp. are also fished across the whole area. The Rockall plateau is subject to an important haddock *Melanogrammus aeglefinus* and small-scale *Nephrops* fishery. Commercial fisheries for cod *Gadus morhua*, plaice *Pleuronectes platessa*, and sole *Solea solea* are conducted in the Irish Sea. The whole area is characterized as a spawning area for a number of key wide-ranging, migratory species, notably mackerel *Scomber scombrus*, horse mackerel *Trachurus trachurus*, and blue whiting *Micromesistius potassou*. These species are also commercially exploited within the area. Key pelagic species on the continental shelf are herring *Clupea harengus*, considered as consisting of a number of different stocks, as well as sardine *Sardina pilchardus* in the southern part of the area, and sprat *Sprattus sprattus*, particularly in the Celtic Sea. The area accommodates considerable stocks of argentines (two species) and also large numbers of small mesopelagic myctophids along the shelf break.

The shelf slope (500–1800 m) comprises a distinct species assemblage, including roundnose grenadier *Coryphaenoides rupestris*, black scabbard fish *Aphanopus carbo*, blue ling *Molva macrophthalma*, and orange roughy *Hoplostethus atlanticus*, as well as deep-sea squalids (sharks) and macrouridae (see Section 3.12). Stock assessments have been mostly unreliable for these species so far. However, strong evidence exists that some stocks have been severely depleted by the deep-water fisheries carried out in this area. All these fish are characterized as being long-lived, slow-growing, and having a low fecundity, making them very vulnerable to overfishing.

More than 170 species of marine fish have been recorded from within the Irish Sea (Ellis *et al*., 2002a). Trawl surveys in this region (Parker-Humphreys, 2004) have revealed that dab *Limanda limanda*, plaice, solenette *Buglossidium luteum*, and common dragonet *Callionymus lyra* are the most abundant species, along with large numbers of poor-cod, whiting, and sole. Dab, solenette, and scaldfish (*Arnoglossus laterna*), all non-commercial species, are thought to have increased in recent years, whereas hake, dragonets, and pogge *Agonus cataphractus* have become less abundant. Red gurnards *Aspitrigla cuculus* are also thought to have increased in recent years.

The Celtic Sea groundfish community consists of over a hundred species and the most abundant 25 comprise 99 percent of the total estimated biomass and around 93 percent of total estimated numbers (Trenkel and Rochet, 2003). Population and community analyses have shown that fishing has impacted a number of commercial species, primarily because individuals of too small a size have been caught and discarded in the past (Trenkel and Rochet, 2003; Rochet *et al*., 2002).The size structure of the fish community has changed significantly over time, and a decrease in the relative abundance of larger fish has been accompanied by an increase in smaller fish (4–25 g) (Blanchard *et al*., 2005; Trenkel *et al*., 2004). Temporal analyses of the effects of fishing and climate variation suggest that fishing has had a stronger effect on size-structure than changes in temperature. A marked decline in mean trophic level of the fish community over time has been documented (Pinnegar *et al.*, 2003), resulting in a reduction in the abundance of large piscivorous fishes such as cod and hake, and an increase in smaller pelagic species which feed at a lower trophic level. Since 1990 the non-exploited species *Capros aper* has become particularly abundant in French and UK survey catches. This phenomenon has been reported as occurring elsewhere in the North Atlantic, including the Bay of Biscay (Farina *et al*., 1997) and offshore seamounts (Fock *et al*., 2002).

Limited information is available for the west coasts of Scotland and Ireland; however, Scottish groundfish surveys between 1997 and 2000 revealed declines in most commercial fish stocks, including haddock, whiting, Norway pout, herring, and hake. Similarly, Irish groundfish surveys revealed a downward trend in the biomass and abundance of cod, whiting, and hake between 1993 and 2000, in particular in the latter part of the time-series. Megrim were somewhat more abundant in recent years, particularly along the coasts of southern Ireland and the Celtic Sea shelf edge (Mahé, 2001).

Demersal elasmobranchs

The Celtic Seas ecoregion covers west of Scotland (Division VIa), Rockall (Division VIb), Irish Sea (Division VIIa), Bristol Channel (Division VIIf), the western English Channel (Division VIIe), and the Celtic Sea and west of Ireland (Divisions VIIb-c, g-k), although the southwestern sector of ICES Division VIIk is contained in the oceanic northeast Atlantic ecoregion. This ecoregion broadly equates with the area covered by the northwestern waters RAC. Whereas some demersal elasmobranchs, such as spurdog *Squalus acanthias* and lesser spotted dogfish *Scyliorhinus canicula*, are widespread throughout this region, there are some important regional differences in the distributions of other species. Other than spurdog and tope, the main species of shark taken in demersal fisheries in this ecoregion are lesser spotted dogfish, smooth-hounds *Mustelus* spp., and greater spotted dogfish *Scyliorhinus stellaris*. Sixteen species of skate and ray are recorded in the area, the most abundant skates being thornback ray *Raja clavata*, cuckoo ray *Leucoraja. naevus*, blonde ray *R. brachyura*, spotted ray *R. montagui*, undulate ray *R. undulata*, common skate *Dipturus batis*, shagreen ray *L. fullonica*, and smalleyed ray *R. microocellata*. Other batoids (stingray *Dasyatis pastinaca*, marbled electric ray *Torpedo marmorata*, and electric ray *T. nobiliana*) may be observed in this ecoregion, although they are more common in more southerly waters. These are generally discarded if caught in commercial fisheries and are not considered in this report.

Landings of rays appear as a series of peaks and troughs, with lows of approximately 14 000 t in the mid-1970s and 1990s, and highs of just over 20 000 t in the early and late 1980s and late 1990s. While landings have fluctuated considerably over the time-series, they have been in a constant decline since 2003, and the 2006 landings of approximately 10 000 t are the lowest in the time-series. This decline in landings is thought to be mainly due to a combination of increased regulation and changes in consumption (ICES, 2007).

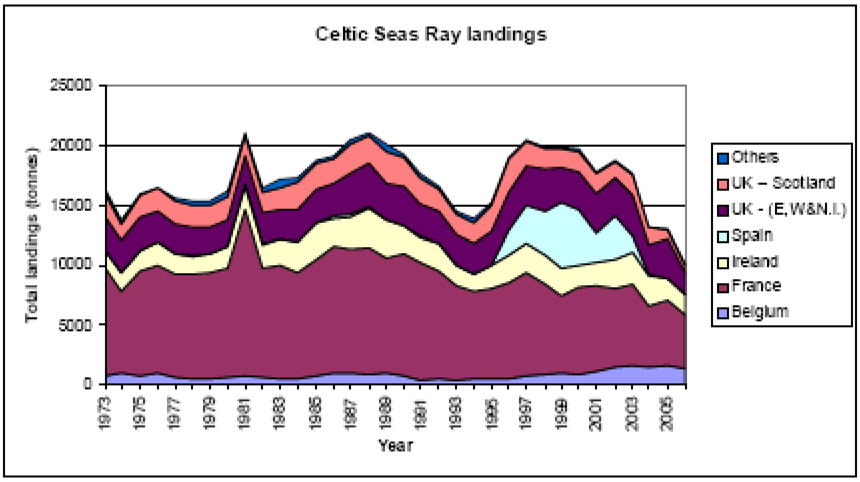

Figure 5.1.4 Demersal elasmobranchs in the Celtic Seas. Total landings (tonnes) of Rajidae by nation in the Celtic Seas from 1973–2006 (Source: ICES).

Trophic web

For the Celtic and Irish Seas, two sources of fish stomach data have recently been collated and these are described by Pinnegar *et al.* (2003). UK researchers collected stomachs for 66 species during annual groundfish surveys from 1986 to 1994. French researchers (du Buit and co-workers) sampled stomachs of seven species aboard commercial fishing vessels, throughout the years 1977 to 1992 (in all seasons).

The main predator species in the Celtic Sea (hake, megrim, monkfish, whiting, cod, saithe) are generalist feeders which exhibit size-dependent, temporal, and spatial prey-switching behaviour (Pinnegar *et al.*, 2003; Trenkel *et al.*, 2005). Consequently, utilization of a conventional multispecies assessment model such as MSVPA in such a system would be unlikely to yield useful insights. Overall, higher prey densities in the environment coincide with higher occurrences of particular prey species in predator stomachs (Trenkel *et al.*, 2005). Blue whiting was found more often in predator stomachs over the shelf edge during the summer months while mackerel and *Triopterus* spp were relatively more prevalent in stomachs sampled on the continental shelf during the winter half-year. Little is known concerning trophic interactions among fish species west of Ireland and northwest Scotland (but see du Buit, 1989, 1991a, 1991b). No major studies of forage fish have been conducted in the ecoregion. Sand eel *Ammodytes* spp., sprat, and Norway pout *Trisopterus esmarki* are known to be present, but their role and importance in the ecosystem remains unclear.

For cod in the Irish Sea, the decapod *Nephrops norvegicus* is known to be an important prey item (Armstrong, 1982). Consequently, Bennett and Lawler (1994) attempted to model cod-*Nephrops*, a simple multispecies model. Whiting, Norway pout, and *Nephrops* are known to be important for monkfish in the Irish Sea (Crozier, 1985). To the northwest of Scotland there have been additional studies focusing on inshore demersal assemblages (e.g. Gibson and Ezzi, 1987).

According to Heath (2005) fish taken from the shelf edge areas of the Celtic Seas tend overall to be less planktivorous and from a higher trophic level than those in the North and Baltic Seas (Heath, 2005). The secondary production required per unit of landed fish from the southern part of the Celtic Seas is suggested to be twice that for North Sea fish. In the Celtic Seas benthos production has been suggested to be a ‘bottom-up’ driver for fisheries production, which seems to be independent of variability in plankton production. As this situation is very different to the situation in the North Sea (see NS section), climate change and fishing pressures might be expected to influence these regional fisheries in very different ways. Overall, there appear to be strong spatial patterns in the fish food web structure and function, which should be important considerations in the establishment of regional management plans for fisheries (Heath, 2005).

Heath (2005) argues that, because the blue whiting fishery is conducted mainly off the continental shelf, there is no rationale for a foodweb connection between the bulk of the blue whiting catch and the other landed species from the Celtic Sea and west of Scotland. However, Pinnegar *et al.* (2003) and Trenkel *et al.* (2005) have both highlighted the importance of this species as a prey for fish on the shelf edge, notably for hake and megrim.

Vulnerable species

Skates are arguably the most vulnerable of exploited marine fishes because of their large size, slow growth rate, late maturity, and low fecundity. Dulvy *et al.* (2000) discussed the disappearance of skate species (*Dipturus oxyrhinchus, Rostooraja alba*, and *D. batis*) in the Irish Sea, and the widespread decline in the abundance of smaller species. In 2006 the Working Group on Fish Ecology (WGFE) evaluated the status of rarer elasmobanchs throughout the ‘Celtic Seas’ ecoregion. The Celtic Sea was highlighted as a particularly important area for common skate (*D. batis*), electric ray (*Torpedo nobiliana*), and shagreen ray (*Leucoraja fullonica*), whereas the English Channel is an important area for undulate ray (*Raja undulata*) and stingray (*Dasyatis pastinaca*) (ICES, 2006b).

The blackspot (red) seabream (*Pagellus bogaraveo*) was previously an important target species of English fisheries in the 1930s (Desbrosses, 1932), catches in the Celtic Seas declining well before the cited collapse of the fishery in region G (see this chapter for a longer account on this species). The species can be considered as commercially extinct in the Celtic Seas.

The red lobster (*Palinurus elephas*) was exploited by pot fisheries prior to the late 1970s, and current catches of this species can be considered as residual.

As mentioned above, several species of deep-water fish are considered as being severely depleted and meriting protection (see Section 3.12).

Birds, mammals, and large elasmobranches

Basking shark (*Cetorhinus maximus*) are seen throughout the Celtic Sea, Irish Sea, and Northern Shelf region, from April through to October, but the stock seems to be severely depleted. Basking shark is protected within British territorial waters. Blue shark (*Prionace glauca*) are found in the summer in the southern part of the area. They are subject to a variety of fisheries, both recreational and directed (longlines and gillnet) as well as bycatch in offshore tuna fisheries. Porbeagle (*Lamna nasus*) and tope (*Galeorhinus galeus*) are also targeted in both recreational and commercial fishing.

Six species of cetaceans are regularly observed in this Advisory Region (Reid *et al*., 2003). Minke whale *Balaenoptera acutorostrata* is found throughout the region, particularly off western Scotland and Ireland. SCAN surveys and observer programmes on ships of opportunity have recorded that bottlenosed dolphin *Tursiops truncatus* occur in large numbers off western and southwestern Ireland and in smaller numbers throughout the region. Common dolphin *Delphinus delphis* are widely distributed in shelf waters, but especially in the Celtic Sea and adjacent areas. White-beaked dolphin and white-sided dolphin (*Lagenorhynchus albirostris* and *L. acutus*) occur over much shelf area, but are less common in the southwest. Harbour porpoise *Phocoena phocoena* is the smallest, but by far the most numerous of the cetaceans found in the Celtic Seas ecoregion, particularly southwest of Ireland and west of Scotland (Hammond *et al*., 2002; Wall *et al*., 2004). Santos *et al*. (2004) suggested that whiting and sandeels are the most important prey for porpoises around the coasts of Scotland, comprising around 80% of the diet.

Grey seals (*Halichoerus grypus*) are common in many parts of the area, with population estimates ranging from approximately 50 000 to 110 000 animals (SCOS, 2005). The majority of individuals are found in the Hebrides and in Orkney, although some 5000–7000 are thought to exist in the Irish and Celtic Seas (Kiely *et al*., 2000). Studies of grey seal diet in the western Irish Sea reveal that the predominant prey species (Norway pout, bib, poor cod, whiting, plaice) are not the principle target species for commercial fisheries in this region (Kiely *et al*., 2000). However, a recent study (Hammond and Harris, 2006) of seal diets off western Scotland revealed that grey seals may be an important predator for cod, herring, and sandeels in this area. Common seals (*Phoca vitulina*) are also widespread in the northern part of the ecoregion with around 15 000 animals estimated (SCOS, 2005). Smaller numbers are seen in Ireland (ca. 4000) and very few further south.

In 2002, the ICES Working Group on Seabird Ecology reported seabird population estimates within all ICES areas. For ICES Division VIa west of Scotland a total of 1.2 million pairs of breeding seabirds were reported. Auks, predominantly the common guillemot (*Uria aalge*), razorbill (*Alca torda*), and the Atlantic puffin (*Fratercula arctica*) accounted for 51% of the total, while petrels (including fulmar (*Fulmarus glacialis),* storm petrel (*Hydrobates pelagicus),* and Manx shearwater (*Puffinus puffinus)*) accounted for 29%, Northern gannet accounted for 10%, and gulls (particularly kittiwake and herring gull) 9% (ICES, 2002). In the Irish Sea, Bristol Channel, and English Channel (ICES Divisions VIIa,d,e,f) gulls predominate (47%, 66%, 90%, and 68%, respectively), in particular black-headed, lesser black-backed and herring gulls as well as guillemots. Petrels (fulmar and storm-petrel) dominate in the west of Ireland and Celtic Sea region (Divisions VIIb,g,j 48%, 60%, and 79%, respectively), but there are also large breeding colonies of kittiwake, guillemot, and gannet. Climate change is likely to impact significantly on seabird populations. The breeding success of some seabird populations in the Celtic Sea has already been linked to climatic fluctuations in the North Atlantic, such as the North Atlantic Oscillation (NAO). Projected consequences of global warming, such as sea level rises, increased storminess, and rises in sea/air temperatures are also likely to have a direct impact on seabird populations.

5.2 Human impacts on the ecosystem

5.2.1 Fishery effects on benthos and fish communities

The impact of fishing activities on shelf fish communities is unclear, although there are numbers of severely depleted stocks e.g. cod, whiting, plaice, and hake. Furthermore, the level of discarding in some fisheries can be significant. Analysis of discarding levels of the demersal fleet around Ireland has shown that a significant proportion of the catch is discarded (Borges *et al.*, 2005). Discarding levels differ between the different fleets but have been shown to be up to two thirds of the total catch. In this study whiting, haddock, megrim, and dogfish are the main species discarded by otter trawlers, while the Scottish seiners discard mostly whiting, haddock, and grey gurnard and beam trawls mostly dab and plaice. The majority of these discard species consist of immature fish and discarding appears to have been increasing in recent years.

Cetacean bycatch in fisheries has been acknowledged to be a threat to the conservation of cetaceans in this ecoregion (CEC, 2002; Ross and Isaacs, 2004). As in other areas this mainly affects small cetaceans, i.e. dolphins, porpoises, and the smaller-toothed whales. Species caught in the region are primarily the harbour porpoise, common dolphin, striped dolphin, Atlantic white-sided dolphin, white-beaked dolphin, bottlenose dolphin, and long-finned pilot whale (CEC, 2002a). However, other larger cetaceans, such as the minke whale, can also be affected.

An extensive review of the bycatch of cetaceans in pelagic trawls was carried out for Greenpeace in 2004 (Ross and Isaacs, 2004). This report considered published and anecdotal information. In the Celtic Seas the report identified a small number of fisheries where cetacean bycatch could be documented. These were:

- Bass fishing in the western Channel;
- Mackerel and horse mackerel trawling SW of Ireland;
- Gillnetting for hake in the Celtic Sea.

In the last two cases, the number of animals caught was low; however, it is probably higher in the bass fishery and has attracted considerable public attention. The report identified that many countries had initiated cetacean bycatch monitoring programmes, and had generally found little or no evidence that serious bycatch had occurred.

Major environmental signals and implications

No obvious environmental signals were identified that should be considered in assessment or management in this area. The major trends in the ecosystem noted above are the steady warming of the area, particularly in the context of the slope current. Surface waters of the Rockall trough have been steadily warming for some years and are currently at an all time high. The general and continuing reduction of copepod abundance and recent changes in zooplankton composition throughout the region are also causes of major concern, given the key role that these organisms play in the food web.

In 2006 the Working Group on the Assessment of Northern Shelf Demersal Stocks (WGNSDS) considered the influence of sea temperatures on cod recruitment (ICES, 2006c) in the Irish Sea. The time-series of Irish Sea cod recruitment exhibited a decline in the 1990s, coincident with an increase in sea surface temperatures (SST). Analysis revealed a clear tendency for strong recruitment residuals to coincide with prominent negative SST residuals, and for weak recruitment to coincide with strong positive SST residuals. Further biological studies are needed to establish the causal mechanisms for any association between cod recruitment residuals and SST, before such an association could be considered to have any predictive power in the future. If causal mechanisms were established, the consequence would be an expectation of a continued high probability of very weak year classes occurring while SSB remains low and SST continues to vary around the elevated values observed since the 1990s. This does not preclude the possibility of strong recruitment occurring in any year, but the probability is likely to be much lower than was the case in the 1960s–1980s when SST was lower and SSB (and consequently egg production) was relatively high.

Increasing temperature and changes in zooplankton communities are likely to have an impact on the life histories of many species. The timing and location of spawning by all species is also likely to be affected by warming, as has been observed in the North Sea (Greve *et al.*, 2001). Southward *et al.* (1988) demonstrated that the abundance of herring *Clupea harengus* and pilchard *Sardina pilchardus* occurring off the southwest of England, closely corresponded with fluctuations in water temperature. Sardine were generally more abundant and extended further to the east when climate was warmer, whilst herring were generally more abundant in cooler times. This pattern has apparently been occurring for at least 400 years, and major changes were noted in the late 1960s as waters cooled and spawning of sardine was inhibited. In recent years herring populations have declined throughout the Celtic Seas ecoregion, but is unclear whether sardine have increased in abundance.

The recent warming trend in the northeast Atlantic has coincided with a northward shift in the distribution of some fish species from southerly waters (Quero *et al*., 1998; Beare *et al*., 2004). Seabass *Dicentrarchus labrax* and red mullet *Mullus surmuletus* populations around British coasts have been growing in recent years. Similarly sightings of blue-fin tuna *Thunnus thynnus*, triggerfish *Balistes capriscus*, thresher *Alopias vulpinus*, and blue sharks *Prionace glauca*, sting-rays, turtles, and seahorses *Hippocampus* spp. are all becoming more commonplace (Stebbing *et al.*, 2002).

Analysis of fish taxa in the western English Channel over a 26-year period indicated that nine species responded strongly to increasing sea temperatures (Genner *et al.*, 2004). A parallel analysis of 33 species in the Bristol Channel over 22 years showed similar macroscopic trends, with one species declining in abundance with warming (the sea snail *Liparis liparis*), and nine increasing (Genner *et al.*, 2004). The widespread and sudden increase in occurrence of non-commercial species such as *Capros aper* in the Celtic Sea particularly after 1990 (Pinnegar *et al*., 2003) might indicate some change in oceanic conditions, as is true of increased sightings of ocean sunfish *Mola mola* (Houghton *et al*., 2006), but mechanisms and consequences are poorly understood.

As is true elsewhere in the NE Atlantic, the Celtic Seas ecoregion has recently experienced an unprecedented increase in the numbers of snake pipefish, *Entelurus aequoreus* (Harris *et al*., in press; Kloppmann and Ulleweit, in press). Kirby *et al*. (2006) speculate that the increased abundance of larval and juvenile *E. aequoreus* in CPR plankton samples as far west as the Mid-Atlantic Ridge may coincide with a rise in winter, spring, and summer sea temperatures (January-September), when the eggs of *E. aqueoreus*, which are brooded by the male, are developing and the larvae are growing in plankton.

Data gaps

In general this ecoregion has attracted less attention than areas such as the North Sea. It is probably not that data do not exist, but that they have not been correlated and integrated. For example, the ICES Annual Ocean Climate Status Summary does not address this area as a whole. The WG would recommend that ICES develops a more integrative approach so that all output data can be matched up easily. The CPR programme samples within the area, but detailed breakdown of these data has not been carried out. There is also no single assessment working group responsible for the fisheries in the region. These are covered by nine different groups, including both northern and southern shelf demersal WGs. This makes the integration of data by ecoregion more complex. There is currently no multi-species working group for this region, and hence there has been no coordinated effort towards exploring predator-prey relationships and inter-dependencies among commercial species.

References

Armstrong, M. J. 1982. The predator-prey relationships of Irish Sea poor-cod (*Trisopterus minutus* L.), pouting (*Trisopterus luscus* L.), and cod (*Gadus morhua* L.). Journal du Conseil International pour l'Exploration de la Mer, 40: 135–152.

Beare, D., Burns, F., Greig, A., Jones E. G., Peach, K., Kienzle, M., McKenzie, E., and Reid, D. G. 2004. Long-term increases in prevalence of North Sea fishes having southern biogeographic affinities. Marine Ecology Progress Series, 284: 269–278.

Bennett, D. B., and Lawler, A. R. 1994. Irish Sea cod and *Nephrops* interactions - can the model be validated? ICES CM 1994/K:34.

Blanchard, J. L., Dulvy N. K., Ellis, J. E., Jennings, S., Pinnegar, J. K. , Tidd, A., and Kell, L. T. 2005. Do climate and fishing influence size-based indicators of Celtic Sea fish community structure? ICES Journal of Marine Science, 62: 405–411.

Borges, L., Rogan, E., and Officer, R. 2005. Discarding by the demersal fishery in the waters around Ireland. Fisheries Research, 76: 1–13.

CEC. 2002. Incidental catches of small cetaceans. Report of the meeting of the subgroup on fishery and the environment (SGFEN) of the Scientific, Technical and Economic Committee for Fisheries (STECF), Brussels December 2001. SEC (2002) 376. Commission of the European Communities, Brussels.

Crozier, W. W. 1985. Observations on the food and feeding of the angler-fish, *Lophius piscatorius* L., in the northern Irish Sea. Journal of Fish Biology. 27: 655–665.

Desbrosses, P. 1932. La dorade commune (*Pagellus centrodontus* Delaroche) et sa pêche. Rev. Trav. Inst. Pêches Marit., 5: 167–222.

Du Buit, M. H. 1989. Quantitative analysis of the diet of cod (*Gadus morhua L.*) off the coast of Scotland. Annales de l'Institut océanographique, Paris. Nouvelle serie, 65: 147–158.

Du Buit, M. H. 1991a. Food and feeding of saithe (*Pollachius virens* L.) off Scotland. Fisheries Research. 12: 307–323.

Du Buit, M. H. 1991b. Food of whiting (*Merlangius merlangus* L., 1758) off Scotland. Cybium, 15: 211–220.

Dulvy, N. K., Metcalfe, J. D., Glanville, J., Pawson, M. G., and Reynolds, J. D. 2000. Fishery Stability, Local Extinctions, and Shifts in Community Structure in Skates. Conservation Biology, 14: 283–293.

Ellis, J. R., Rogers, S. I., and Freeman, S. M. 2000. Demersal assemblages in the Irish Sea, St George's Channel and Bristol Channel. Estuarine, Coastal and Shelf Science, 51: 299–315.

Ellis, J. R., Lancaster, J. E., Cadman, P. S., and Rogers, S. I. 2002. The marine fauna of the Celtic Sea. *In* Marine biodiversity in Ireland and adjacent waters (Ed. by J. D. Nunn). Ulster Museum, Belfast, 45–65.

Ellis, J. R., Armstrong, M. J., Rogers, S. I., and Service, M. 2002a. The distribution, structure and diversity of fish assemblages in the Irish Sea, pp .93–114. *In* Marine Biodiversity in Ireland and adjacent waters. Proceedings of the E.C.S.A. Conference (Ed. by J. D. Nunn). Ulster Museum, Belfast.

Farina, A. C., Freire, J., and Gonzalez-Gurriaran, E. 1997. Demersal fish assemblages in the Galician continental shelf and upper slope (NW Spain): Spatial structure and long-term changes. Estuarine, Coastal and Shelf Science, 44, 435–454.

Fernand, L., Nolan, G. D., Raine, R., Chambers, C. E., Dye, S. R., White, M., and Brown, J. 2006. The Irish coastal current: a seasonal jet-like circulation. Coastal Shelf Research, 26: 1775–1793.

Fock, H., Uiblein, F., Köster, F., and von Westernhagen, H. 2002. Biodiversity and species-environment relationships of the demersal fish assemblage at the Great Meteor Seamount (subtropical NE Atlantic), sampled by different trawls. Marine Biology, 141: 185–199.

FRS. 2005. Scottish Ocean Climate Status Report 2002–2003. Fisheries Research Services, Aberdeen.

Genner, M. J., Sims, D. W., Wearmouth, V. J., Southall, E. J., Southward, A. J., Henderson, P. A., and Hawkins, S. J. 2004. Regional climate warming drives long-term community changes of British marine fish. Proceedings of the Royal Society of London series B – Biological Sciences, 271**:** 655–661.

Gibson, R. N., and Ezzi, I. A. 1987. Feeding relationships of a demersal fish assemblage on the west coast of Scotland. Journal of Fish Biology, 31: 55–69.

Greve, W., Lange, U., Reiners, F., and Nast, J. 2001. Predicting the seasonality of North Sea zooplankton. *In* Burning Issues of North Sea Ecology, Proceedings of the 14th International Senckenberg Conference North Sea 2000, pp. 263–268. Ed. by I. Kröncke, M. Türkay, and J. Sündermann. Senckenbergiana Maritima, 31(2).

Harris, M. P., Beare, D., Toresen, R., Nøttestad, L., Kloppmann, M., Dörner, H., Peach, K., Rushton, D. R. A., Foster-Smith, J., and Wanlass, S. (in press). A major increase in snake pipefish (*Entelurus aequoreus*) in northern European seas since 2003: potential implications for seabird breeding success. Marine Biology.

Hammond, P. S., Berggren, P., Benke, H., Borchers, D. L., Collet, A., Heide-Jørgensen, Heimlich, S., Hiby, A. R., Leopold, M.F., and Øien, N. 2002. Abundance of harbour porpoise other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology, 39: 361–376.

Hammond, P. S., and Harris, R. N. 2006. Grey seal diet composition and prey consumption off western Scotland and Shetland. Final Report to Scottish Executive, Environment and Rural Affairs Department and Scottish Natural Heritage.

Heath, M. R. 2005. Regional variability in the trophic requirements of shelf sea fisheries in the northeast Atlantic, 1973-2000. ICES Journal of Marine Science, 62: 1233–1244.

Houghton, J. D. R., Doyle, T. K., Davenport, J., and Hays, G. C. 2006. The ocean sunfish *Mola mola*: insights into distribution, abundance and behaviour in the Irish and Celtic Seas. Journal of the Marine Biological Association of the United Kingdom, 86: 1237–1243.

ICES. 2002. Report of the Working Group on Seabird Ecology (WGSE). ICES CM 2002/

ICES. 2006. ICES Report on Ocean Climate 2005. ICES Cooperative Research Report, 280. 49 pp.

ICES. 2006a. Zooplankton monitoring results in the ICES area: summary status report 2004/2005 ICES Cooperative Research Report, 281. 43pp.

ICES. 2006b. Report of the Working Group on Fish Ecology (WGFE). ICES CM 2006/LRC:06.

ICES. 2006c. Report of the Working Group on the Assessment of Northern Shelf Demersal Stocks (WGNSDS). ICES CM 2006/ACFM:30.

ICES. 2007. Report of the Working Group on Elasmobranch Fishes (WGEF). ICES CM 2007/ACFM:27.

Joyce, A. E. 2006. The coastal temperature network and ferry route programme: long-term temperature and salinity observations. Sci. Ser. Data Rep., Cefas Lowestoft, 43: 129 pp.

Kaiser, M. J., Bergmann, M., Hinz, H., Galanidi, M., Shucksmith, R., Rees, E. I. S., Darbyshire, T., and Ramsay, K. 2004. Demersal fish and epifauna associated with sandbank habitats. Estuarine, Coastal and Shelf Science, 60: 445–456.

Kirby, R. R., Johns, D. G., and Lindley, J. A. 2006. Fathers in hot water: rising sea temperatures and a Northeastern Atlantic pipefish baby boom. Biology Letters, 2: 597–600.

Kloppmann, M. H. F., and Ulleweit, J. (in press) Off-shelf distribution of pelagic snake pipefish, *Entelurus aequoreus* (Linnaeus, 1758), west of the British Isles. Marine Biology.

Kiely, O., Ligard, D., MvKibben, M., Connolly, N., and Baines, M. 2000. Grey seals: status and monitoring in the Irish and Celtic Seas. Maritime Ireland/Wales INTERREG Report Number 3. The Marine Institute, Dublin. 76 pp.

Lordan, C. 2001. The distribution and abundance of cephalopod species caught during demersal trawl surveys west of Ireland and in the Celtic Sea. Irish Fisheries Investigations B, 8, 26 pp.

Mahé, J-C. (ed.). 2001. International Program of Standardised Trawl Surveys (IPROST). Study EC-DGXIV No. 98–0587. Ifremer-Marine Laboratory-Marine Institute. 122 pp.

Nash, R. D. M., and Geffen, A. J. 2004. Seasonal and interannual variation in abundance of *Calanus finmarchicus* (Gunnerus) and *Calanus helgolandicus* (Claus) in inshore waters (west coast of the Isle of Man) in the central Irish Sea. Journal of Plankton Research, 26: 265–273.

Nolan, G. D., and Lyons, K. 2006. Ocean climate variability on the western Irish Shelf, an emerging time-series. ICES CM 2006/C:28.

OSPAR. 2000. Quality Status Report 2000. OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic, London.

Parker-Humphreys, M. 2004. Distribution and relative abundance of demersal fishes from beam trawl surveys in the Irish Sea (ICES Division VIIa) 1993-2001. Sci. Ser. Tech Rep., CEFAS Lowestoft, 120: 68 pp.

Pinnegar, J. K., Trenkel, V. M., Tidd, A. N., Dawson, W. A., and Du Buit, M. H. 2003. Does diet in Celtic Sea fishes reflect prey availability? Journal of Fish Biology, 63 (Suppl. A): 197–212.

Quero, J. C., Du Buit, M. H., and Vayne, J. J. 1998. Les observations de poissons tropicaux et le rechauffement des eaux de l'Atlantique europeen. Oceanologica Acta, 21: 345–351.

Raine, R., White, M., and Dodge, J. D. 2002. The summer distribution of net plankton dinoflagellates and their relation to water movements in the NE Atlantic Ocean, west of Ireland. Journal of Plankton Research, 24(11): 1131–1147.

Rees, H. L., Pendle, M. A., Waldock, R., Linpenny, D. S., and Boyd, S. E. 1999. A comparison of benthic biodiversity in the North Sea, English Channel and Celtic Seas. ICES Journal of Marine Science, 56: 228–246.

Reid, D. G., Walsh, M., and. Turrell, W. R. 2001a. Hydrography and mackerel distribution on the shelf edge west of the Norwegian deeps. Fisheries Research, 50: 141–150.

Reid, J. B., Evans, P. G. H., and Northridge, S. P. 2003. Atlas of Cetacean distribution in north-west European waters. Joint Nature Conservancy Committee, Peterborough, UK.

Rochet, M-J., Péronnet I., and Trenkel, V. M. 2002. An analysis of discards from the French trawler fleet in the Celtic sea. ICES Journal of Marine Science, 59: 538–552.

Santos, M. B., Pierce, G. J., Learmonth, J. A., Reid, R. J., Ross, H. M., Patterson, I. A. P., Reid, D. G., and Beare, D. 2004. Variability in the diet of harbour porpoises (*Phocoena phocoena*) in Scottish waters 1992–2003. Marine Mammal Science, 20: 1–27.

SCOS. 2005. Scientific Advice on matters related to the management of seal populations: 2005. Special Committee on Seals (SCOS). smub.st.and.ac.uk/CurrentResearch.htm/ SCOS%2005_v2f.pdf.

Silke, J., O'Beirn, F., and Cronin, M. 2005. *Karenia mikimotoi*: An Exceptional Dinoflagellate Bloom in Western Irish Waters-Summer 2005. Marine Environment and Health Series, 23: 11-21.

Southward, A. J., Boalch, G. T., and Maddock, L. 1988. Fluctuations in the herring and pilchard fisheries of Devon and Cornwall linked to change in climate since the 16th Century. Journal of the Marine Biological Association of the United Kingdom, 68: 423–445.

Stebbing, A. R. D., Turk, S. M. T, Wheeler, A., and Clarke, K. R. 2002. Immigration of southern fish species to south-west England linked to warming of the North Atlantic (1960–2001). Journal of the Marine Biological Association of the United Kingdom, 82: 177–180.

Trenkel, V. M., Pinnegar, J. K., Dawson, W. A., Du Buit, M. H., and Tidd, A. N. 2005. Spatial and temporal predation patterns in the Celtic Sea. Marine Ecology Progress Series, 299: 257–268.

Trenkel, V. M., Pinnegar, J. K., Rochet, M-J., and and Rackham, B. 2004. The effect of different survey designs on population and community indicators for the Celtic sea groundfish community. ICES Journal of Marine Science. 61: 351–362.

Trenkel, V. M., and Rochet, M-J. 2003. Performance of indicators derived from abundance estimates for detecting the impact of fishing on a fish community. Canadian Journal of Fisheries and Aquatic Sciences, 60: 67–85.

Wall, D., O'Brien J., Meade, J., and Allen, B. M. 2004. Summer distribution and relative abundance of cetaceans off the west coast of Ireland. Biology & Environment: Proceedings of the Royal Irish Academy, 106B(2): 135–142.

Young, E. F., Brown, J., Aldridge, J. N., Horsburgh, J. K., and Fernand, L. 2004 Development and application of a three-dimensional baroclinic model to the study of the seasonal circulation in the Celtic Sea. Continental Shelf Research, 24: 13–36.