32. Celtic Sea frontal systems

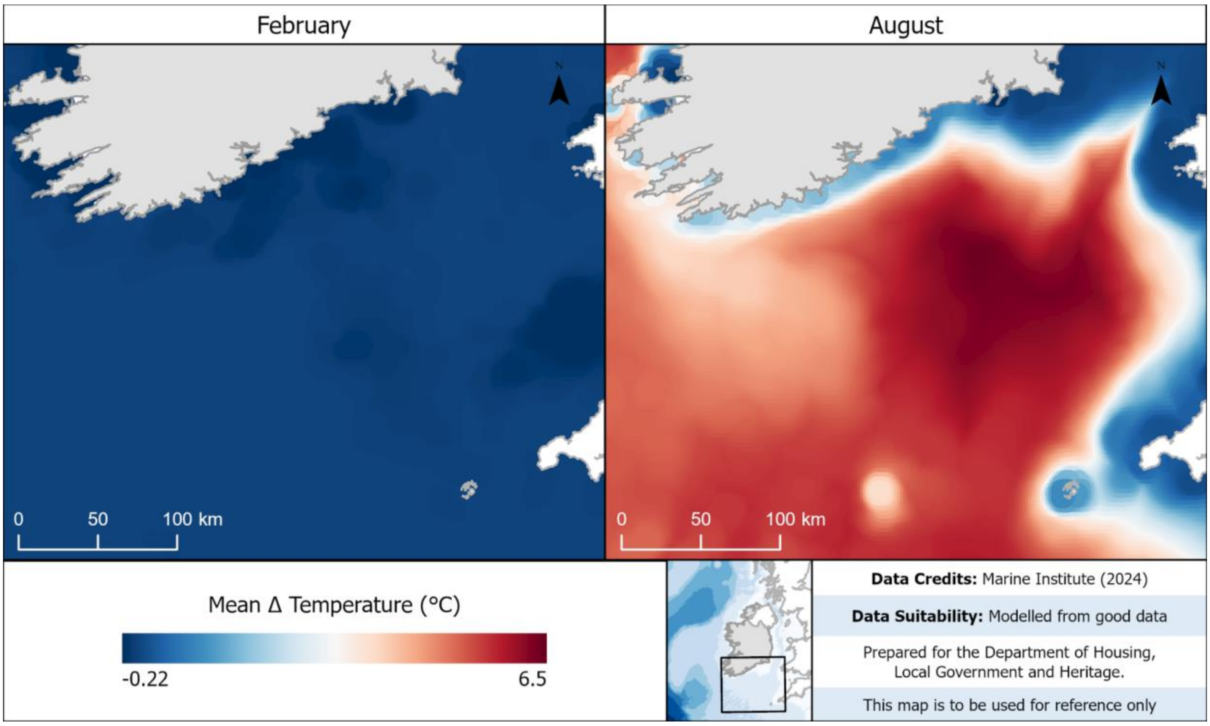

Figure A10.32.1. Temperature difference between surface and bottom water during February when the water column is mixed, and during August when the water column is well stratified as a result of solar warming.

Background

Fronts occur across a range of horizontal scales, from a few metres to thousands of kilometres; some fronts are transient, lasting hours or days (e.g., tidal fronts), while others are permanent oceanic features, like the western shelf edge front off the Irish west coast. Within the Celtic Sea, there are several persistent seasonal thermohaline fronts that develop in late spring/early summer every year, one of which is the Celtic Sea Front. However, all these fronts are in fact part of a single contiguous frontal system, which drives a coastal current around the entire periphery of the Celtic Sea, from the southwest of Biscay Bay to Mizen Head, and indeed this current continues along the west coastline northward onto the Scottish shelf.

During the winter months, all water in the Celtic Sea is vertically mixed, predominantly because of high tidal energy in the region. As days become longer and warmer during spring, solar radiation heats the surface layer and a distinct pycnocline (a sharp density gradient) forms separating the cold dense bottom water (winter water) from the warm surface water in approximately the top 20 - 30 m (Brown *et al.*, 2003; Fernand *et al.*, 2006; Hill *et al.*, 2008; Raine, 2014). Nearer the coastline, in shallower areas, tidal energy is more intense and prevents stratification of the water column, which remains vertically mixed. The boundary between the offshore warm stratified water and the inshore tidally mixed water is the frontal zone. In addition, the difference in density across the front in combination with the Coriolis effect creates an anticlockwise rotation around the cold dense bottom water which drives a westward flowing current across the front (Hill et al., 2008). This coastal current, sometimes referred to as a ‘coastal jet’ is a distinct narrow body of water flowing along the nearshore side of the front, above the pycnocline . The development and persistence of the frontal systems during the summer months, and the gradual return to mixed waters from October onwards is shown in Figure A10.32.2 (cf. Figure A10.32.1 first panel for the mixed waters of winter months, as illustrated by February).

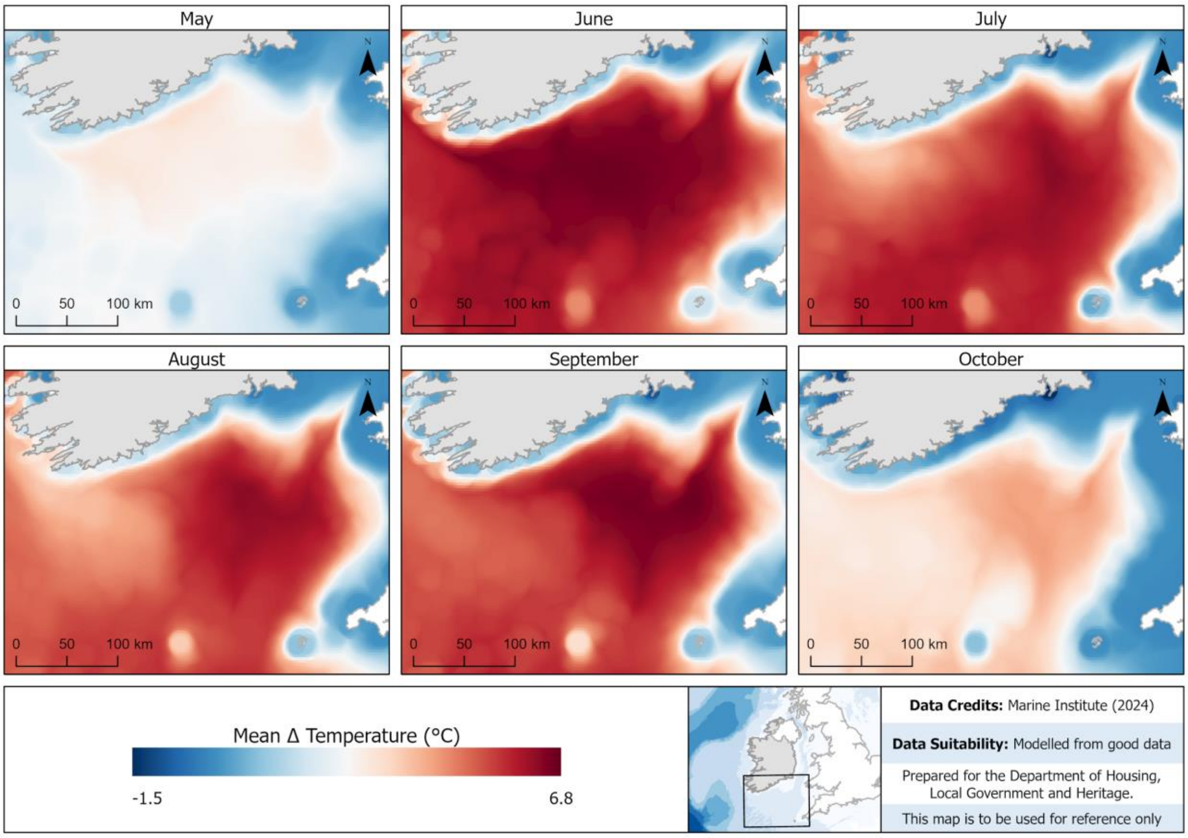

Figure A10.32.1. Temperature difference between surface and bottom water during May to October showing the water column becoming well stratified as a result of solar warming.

All tidal fronts are recognised as ecologically significant because they are regions of high biological activity across all trophic levels, from phytoplankton to large apex predators (Acha, 2015; Belkin et al., 2009). The physical processes of the front increase the availability of nutrients and can aggregate phytoplankton near the surface, driving an increase in primary productivity. This increase in biomass drives a bottom up effect, as the increased biomass flows upward through the pelagic food web, until reaching large megafauna, i.e., sharks, seabirds and marine mammals.

Rationale for spatial protection in the Celtic Sea

The Celtic Sea frontal systems are areas of recognised ecological importance. Frontal systems in the Celtic Seas began to be described scientifically in the 60s and 70s when research cruises and satellite imagery were able to reveal discrete changes in temperature, salinity and chlorophyll *a* (Simpson and Hunter, 1974; Fearnhead, 1975; Pingree, 1976; Pingree and Griffiths, 1978). Early observations indicated that zooplankton, fish eggs (ichthyoplankton) and phytoplankton (chlorophyll *a*) increase at Celtic Sea fronts (Savidge, 1976 ; Le Fevre, 1987). Indeed, copepod eggs are also found in increased abundance in sediments near fronts (Lindley, 1990). For many years, fishers have used fronts to target aggregations of tuna and squid (Le Fevre, 1987), and baleen whales have been observed feeding on forage fish and crustaceans aggregated at fronts (Owen, 1984). Specific examples of species and Celtic Sea front associations include Manx shearwaters *Puffinus puffinus* (Stone et al.,1994), Gannets *Morus bassana* (Cox et al., 2016) common dolphins *Delphinus delphis* (Goold, 1998), cuttlefish *Sepia officinalis* (Wang et al., 2003), basking sharks *Cetorhinus maximus* (Southall et al., 2005; Sims and Quayle, 1998) and blue sharks *Prionace glauca* (Queiroz et al., 2012).

Celtic Sea frontal systems have a profound influence over the character and ecology of the Celtic Sea. While frontal systems generally form where two distinct water masses meet, this image does little to convey the complexity and dynamics involved. Celtic Sea fronts are in constant flux with lateral and vertical flows, which can be influenced by tides and local wind conditions. This leads to mixing and an increase in the availability of nutrients, e.g., nitrogen. As a result, primary productivity, measured by chlorophyll *a*, is higher at the Celtic Sea Front when compared with the rest of the Celtic Sea, with peak values found subsurface near the thermocline (Pingree et al., 1976; Sharples et al., 2011; Hickman et al., 2012). While converging currents can aggregate plankton at the fronts, inevitably, plankton is dispersed by the lateral flows, known as the coastal current, as described above. The coastal current also moves shellfish larvae, zooplankton and harmful algal blooms westward along the front, with the latter two often becoming problematic for aquaculture in the southwest bays of Ireland (Gough, 1905; Cosica et al., 2012; Raine et al., 2014). In fact, the Celtic Sea fronts act as a conveyor or highway, moving plankton, nutrients, and pollution around the periphery of the Celtic Sea, from Biscay to the southwest of Ireland (Brown et al., 2003; Fernand et al., 2006; Hill et al., 2008). It is also likely that the Celtic Sea Front is vital in maintaining the nephrops fishing, firstly by polarising tidal flows around the nephrops grounds, reducing resuspension, and maintaining a muddy substrate. Secondly, the anti-clockwise rotation may form a gyre which retains nephrops larvae within the area, analogous to the Western Irish Sea gyre (Sharples et al., 2013).

In addition, the Celtic Sea frontal systems partitions the Celtic Sea for approximately 5 months of the year, separating the tidally mixed coastal fringe from the warm stratified central regions, forming a putative barrier between two different pelagic communities. The warm stratified regions are characterised by oceanic plankton containing abundant molluscs, Hydrozoa and other holoplankton, while the coastal fringe is characterised by a high diversity of meroplankton such as decapods, polychaetes and scyphozoan jellies (Haberlin et al., 2019), although some copepod species are ubiquitous across both communities (McGinty et al., 2014). While the front is not a barrier to fish, it may nonetheless influence their distribution and behaviour because it is shaping the zooplankton communities (and species) upon which fish, seabirds and marine mammals feed.

The Celtic Sea frontal systems have a substantial effect on sound propagation by damping sound levels. Sound produced in the nearshore area during summer is concentrated near the bottom, whereas in the winter the sound propagates more uniformly through the entire water column (Shapiro and Thain, 2014). Also, sound transmitted on the offshore side of the front propagates more uniformly through the water column. The transmission loss is as high as 20 dB at a distance of 30-40 km (Shapiro and Thain, 2014). As underwater noise is classed as a pollutant (Directive 2008/56/EU), the spatial and temporal presence of the front has serious implications for managing both ship and impulsive (e.g. pile driving) sounds and their potential impacts on sensitive species.

The Celtic Sea frontal systems are not protected and/or managed under any current legislation. The Celtic Sea Front is not protected by current legislation, however, protection of all pelagic habitats is included in the Marine Strategy Framework Directive (Directive 2008/56/EU). Several of the eleven qualitative descriptors in the MSFD relate to pelagic habitats and arguably support protection of frontal systems as a component of Good Environmental Status more generally in the Celtic Sea.

Descriptor 1 - *Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.*

Descriptor 4 - *All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.*

Descriptor 7 – *Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.*

Descriptor 11 – *Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.*

The Celtic Sea frontal systems are amenable to spatial protection, which in turn, also confers protection on a broad range of species which use the front.

The Celtic Sea frontal systems are predictable both temporally and spatially and while the front is malleable, responding to local climate, weather and tides, these fluctuations do not significantly alter the position of the front which is closely linked to the underlying continental shelf topography. There is a robust body of evidence demonstrating that multiple sensitive species, e.g., basking sharks, aggregate along fronts to take advantage of enhanced foraging opportunities (Southall et al., 2005; Sims and Quayle, 1998). The ecological importance of frontal systems is widely recognised now by their inclusion in a number of marine protected areas in several jurisdictions, setting a precedent for MPA designation based on one or more sensitive features. A candidate Marine Conservation Zone (MCZ) near the Celtic Sea Front, called the Celtic Deep MCZ is under consideration for the protection of pelagic and benthic habitats (https://consult.defra.gov.uk/marine/tranche2mczs/). Part of the Irish Sea Front is designated an SPA to protect Manx Shearwater which forage in the frontal zone (https://mpa.ospar.org/home-ospar/mpa-datasheets/an-mpa-datasheet-en?wdpaid=555637379&gid=4105).

Sensitivity assessment

The sensitivity assessment was based on seven ecological groups considered important within the Celtic Sea frontal systems (Table A10.32.1). Each ecological group was assessed based on the sensitivity of characterising taxa, i.e. taxa which have the ecology and life history that characterise all members of the group. Where sensitivities differed between ecological groups, the highest sensitivity value was taken for the overall sensitivity assessment. For further details on the sensitivity assessment protocol for the Celtic Sea frontal systems refer to Appendix 5d, 5d.5.1.1.

Table A10.32.1. Ecological groups of the Celtic Sea frontal systems and the taxa which characterise them. Characterising taxa may be a representative species, a family or a broader taxonomic grouping, such as calanoid copepods. For further methodological details of the sensitivity assessment see Appendix 5d.

Ecological groups	Characterising taxa

Phytoplankton - Photosynthesising and heterotrophic phytoplankton	Class Bacillariophyceae (diatoms) Class Mastigophora (dinoflagellates)
Mesozooplankton - Heterotrophic mero and holo-zooplankton (2µm - 2 cm size)	Class Copepoda, Order Calanoida
Macrozooplankton - Heterotrophic mero and holo-zooplankton (> 2 cm size)	*Rhizostoma pulmo* - barrel jelly (Phylum Cnidaria, Class Scyphozoa, Order Rhizostomeae)
Planktivorous fish - Mid trophic level forage fish species	Order Clupeiformes including herring, sardine and anchovy
Large planktivorous fish	*Cetorhinus maximus* (basking shark)
Benthic predatory fish Demersal high trophic level predators	Family Rajidae: *Dipturus batis/intermedius* - 'common skate complex', flapper and blue skate
Pelagic predatory fish - Mid to surface water column high trophic level predators	Order Charchariniformes, Lamniformes - *Lamna nasus* (porbeagle shark)

Celtic Sea frontal systems are highly sensitive to the pressure physical loss (to land or freshwater habitat) associated with the construction and operation of offshore wind farms. All marine habitats and benthic species are considered to have a resistance of None to this pressure and to be unable to recover from a permanent loss of habitat (resilience is very low)(high confidence)(Tyler-Walters et al., 2018).

Celtic Sea frontal systems are highly sensitive to the pressures, removal of target species and removal of non-target species, both of which are associated with fishing activities.

Data sources available

Data sources for Celtic Sea frontal systems in the Celtic Sea AOI that were available to the MPA Advisory Group, and the quality / suitability of those data for conservation prioritization analyses (See Table 3.2.1 Main Report), are shown in Figure A10.32.1. For information on how data were prepared for use in prioritization analyses, and for visualisation of layer used, see Appendix 5e, section 5e.4

Further research needs

While the ecological importance of frontal systems is accepted, there are large knowledge gaps with regards to quantifying the influence of fronts on continental shelf ecosystems. Quantifying the influence of fronts on the flow of biomass and nutrients is challenging and while satellite sensors have enabled huge spatial coverage, there remains a lack of *in situ* sampling and monitoring with which to validate remote sensors. The flow of energy and biomass from phytoplankton to zooplankton and upward through the food web is likewise, not clearly understood. Within the Irish EEZ and the Celtic Sea, only a small number of studies have investigated zooplankton communities and their spatial distribution, providing snapshots in time. A more coherent temporal sampling strategy is needed to fully understand the seasonal and interannual changes in the Celtic Sea, and how it is influenced by fronts.

Many zooplankton and higher trophic level forage fish are likely closely linked to frontal processes, while also forming an important prey field for more mobile megafauna. As fronts evolve with climate change, possibly increasing in intensity, shifting location and altering vertical nutrient exchange across the Celtic Sea, this is likely to have consequences for megafauna which remain difficult to predict at this time.

The installation of offshore renewable energy infrastructure presents many unknowns in the Celtic Sea. The infrastructure, in the form of fixed bottom wind farms is unlikely to change the physical functioning of the Celtic Sea fronts, however, the creation of artificial reefs, possible OECMs, wind shear, wake effects and reduced surface currents within wind farms, might have biological consequences.

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