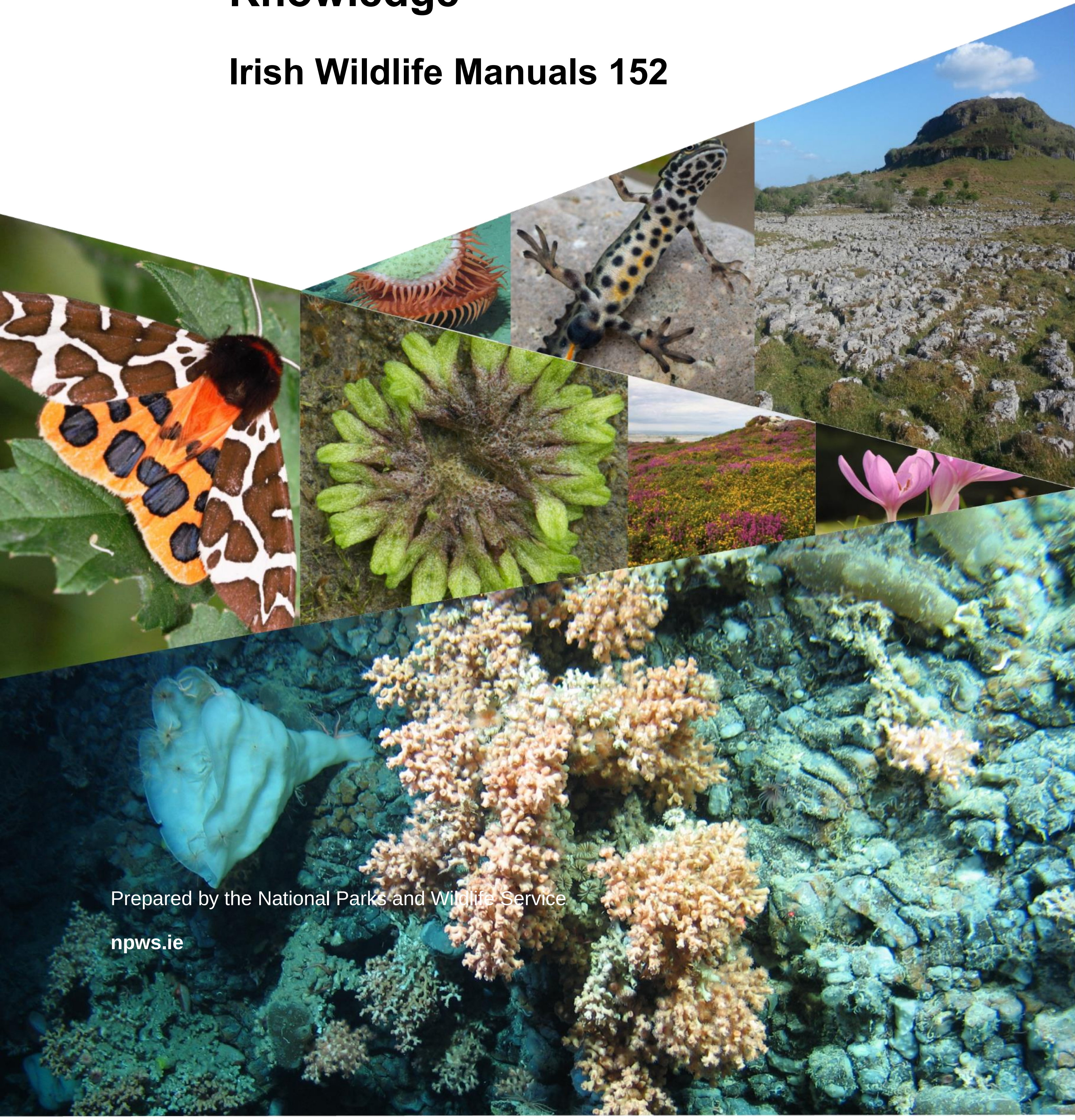
An tSeirbhís Páirceanna Náisiúnta
agus Fiadhúlra
National Parks and Wildlife Service

Reef Habitat in Irish Offshore Waters – A Synthesis of Current Knowledge

Irish Wildlife Manuals 152



Prepared by the National Parks and Wildlife Service

npws.ie

Citation: Forde, J., Alcock, L. & Grehan, A. (2024). Reef habitat in Irish Offshore Waters – A synthesis of current knowledge. Irish Wildlife Manuals, No. 152. National Parks and Wildlife Service, Department of Housing, Local Government and Heritage, Ireland.

Keywords: Reefs, Cold-water Coral, *Lophelia*, Biogenic, Geogenic, Ireland, Irish Offshore Waters, Habitats Directive.

Front cover, small photographs from top row:

A deep water fly trap anemone *Phelliactis* spp., Yvonne Leahy; **Common Newt** *Lissotriton vulgaris,* Brian Nelson; **Limestone pavement**, Bricklieve Mountains, Co. Sligo, Andy Bleasdale; **Garden Tiger** *Arctia caja,* Brian Nelson; **Violet Crystalwort** *Riccia huebeneriana*, Robert Thompson; **Coastal heath**, Howth Head, Co. Dublin, Maurice Eakin; **Meadow Saffron** *Colchicum autumnale*, Lorcan Scott

Bottom photograph: ***Desmophyllum pertusum*** on Porcupine Shelf, Yvonne Leahy

Reef Habitat in Irish Offshore Waters – A Synthesis of Current Knowledge

Authors: James Forde[1], Louise Alcock[2] & Anthony Grehan[2]

Author's affiliation: [1]RPS, Lyrr 2, IDA Business and Technology Park, Mervue, Galway. [2]National University of Ireland, Galway

The NPWS Project Officer for this report was: Lucy Harding (lucy.harding@npws.gov.ie) and David Lyons (David.lyons@npws.gov.ie)

This IWM was edited by Sue Wilson and Domhnall Finch

ISSN 1393 – 6670

An Roinn Tithíochta, Rialtais Áitiúil agus Oidhreachta, 90 Sráid an Rí Thuaidh, Baile Átha Cliath 7, D07 N7CV

Department of Housing, Local Government and Heritage, 90 North King Street, Dublin 7, D07 N7CV

Contents

Executive Summary

Reef habitats are highly important marine habitats, noted for their structural role, and the ability to enhance the diversity and abundance of marine fauna, increase habitat complexity and create opportunities for ecological interactions. The European Union Habitats Directive (92/43/EEC) provides legal protection for a range of habitats and species. Under the Directive, member states are obliged to introduce measures for the protection and surveillance of the Conservation Status (a measure of the long-term survivability) of those habitats and species. Member states are required to implement Special Areas of Conservation (SACs) that support and protect habitats listed in Annex I and species listed in Annex II of the Directive. One such Annex I habitat is ‘Reefs’ (Habitat Code: 1170). Under Article 17 of the Directive member states must report every six years to the European Commission on the Conservation Status of the listed habitats and species, and on the implementation of the measures taken to ensure their protection. In April 2019, Ireland submitted the third assessment of conservation status for 59 habitats and 60 species (NPWS, 2019a, b).

In Irish marine waters reef habitats are widespread, extending from the intertidal zone to water depths of 4,500 m, and more than 400 km offshore. Reefs comprise of hard substrates that rise from the seabed. Reef can be categorised as being geogenic or biogenic. In deep offshore water, defined here as continental shelf waters greater than 200 m in depth, biogenic reefs are typically formed by the accumulations of dead or living hard bodied animals. These include cold-water coral reef species, which can accumulate over millions of years to form carbonate mound structures, that measure up to 5 km across and rise up to 350 m above the seafloor. In offshore waters geogenic reef includes exposed rocky substrate, including boulder and cobble fields, that can provide substrate for colonisation by fauna including coral species. These offshore biogenic and geogenic reef habitats support diverse communities comprising of anemones, sponges, crustaceans and fish.

The resilience of reef habitat to disturbance, particularly offshore reef, is low with even small levels of pressure, particularly from bottom-trawl fishing, likely to have adverse impacts on the ecological quality and Conservation Status of the habitat. Given the low tolerance of this habitat, the Overall Status of the Annex I Habitat Reef (1170) was assessed in Ireland’s 2013 Habitats Directive Article 17 Assessment as Unfavourable/Bad with an ongoing decline and assessed as Inadequate/Stable during Ireland’s 2019 Article 17 assessment, primarily due to poor future prospects of structure and functions, as a result of the low tolerance of reef habitat to physical disturbance. There were significant knowledge gaps with regard to offshore reef habitat distribution, extent and ecology, and the potential pressures effecting the conservation and survival of reef species and associated communities. The objective of this project was to address these knowledge gaps and increase the knowledge base for the national assessment of offshore reef.

The objective of this project was to compile a desk-study report on the distribution, ecological requirements, and resilience of offshore geogenic and biogenic cold-water coral reef habitat in Irish offshore waters. This report also outlines the policies influencing the protection and conservation status of offshore reef habitats in Irish waters and makes recommendations of future work that could be beneficial for the conservation status of offshore reefs.

1 Introduction

1.1 Background

The European Union (EU) Directive on the Conservation of Habitats, Flora and Fauna (92/43/EEC) (Council Directive, 1992), commonly known as the Habitats Directive, is a legislative instrument that allows for the establishment of a common framework for the conservation of a network of Special Areas of Conservation (SACs) to help '*maintain and restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest'* listed in Annex I, II and IV of the Directive.

Article 1(e) of the Habitats Directive defines the Conservation Status of a habitat as '*the sum of influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species*'. Based on this definition, Conservation Status is determined by a combination of the present state of a habitat in terms of its area, range, structure and functions, and the current environmental factors and human influences (or pressures), both positive and negative, that may influence the long-term survival (or prospect) of the habitat and its associated species/communities. Consequently, natural habitats are considered to be achieving Favourable Conservation Status (FCS) when:

i. the habitat's natural range and areas it covers within that range are stable or increasing, and;

ii. the specific structure and functions, which are necessary for its long-term maintenance, exist and are likely to continue to exist for the foreseeable future; and,

iii. the conservation status of its typical species is favourable (as defined below).

Under the Habitats Directive each EU Member State (MS) is obliged to introduce a range of measures for the protection and surveillance of the Conservation Status of habitats listed in Annex I of the Directive, and, under Article 17 of the Directive, to report to the European Commission (EC) every six years on the Conservation Status of those habitats and on the implementation of the measures taken under the Directive to ensure their protection.

In April 2019, Ireland's Department of Culture, Heritage and the Gaeltacht submitted the third national Article 17 assessment of conservation status for 59 habitats and 60 species (including three overview assessments of species at a group level). This report identified the area, range, structure and functions, and future prospects of 59 Annex I habitats and evaluated their Conservation Status (NPWS, 2019a, b). The Annex I habitat Reef (Habitat Code: 1170) was included in this report.

Reef (1170) is defined in the *Interpretation Manual of European Habitats* (EC, 2013) as hard compact substrates on solid and soft bottoms that rise from the seabed in the littoral and sublittoral zones. In Irish marine waters reef habitats are widespread and represent a significant resource within Ireland's Exclusive Economic Zone (EEZ), extending from the intertidal zone to water depths of 4,500 m, and more than 400 km offshore (NPWS, 2019a). Reef can be broadly categorised based on its mode of origin as geogenic or biogenic (European Commission, 2013). Biogenic reefs are formed by encrustations, corallogenic concretions and bivalve beds originating from dead or living animals, while geogenic reef are formed by non-biogenic rocky substrata.

In Irish offshore waters, defined here as continental shelf waters greater than 200 m in depth, biogenic reef habitats may be formed by aggregations of hermatypic (reef-forming) cold-water coral species, while geogenic rocky reef habitats include submarine canyon vertical rock walls, horizontal ledges and overhangs, seamounts, and boulder and cobble fields (Guinan & Leahy, 2009; Johnson *et al*., 2013).

The resilience of reef habitat to disturbance, particularly offshore reef, is low with even small levels of pressure, particularly from bottom-trawl fishing, likely to have adverse impacts on the ecological quality and Conservation Status of the habitat. Given the low tolerance of this habitat, the Overall Status of the Annex I Habitat Reef (1170) was assessed in Ireland's 2013 Habitats Directive Article 17 Assessment as Unfavourable/Bad with an ongoing decline (NPWS, 2013a, b) and assessed as Inadequate/Stable during Ireland's 2019 Article 17 assessment, primarily due to poor future prospects of structure and functions, as a result of the low tolerance of reef habitat to physical disturbance (NPWS, 2019a, b).

It was noted in the 2013 Article 17 Assessments that there were significant data gaps in relation to elements that contributed to the area/range (spatial data), structure and functions, and potential pressures, components of the Conservation Status assessment for offshore reef habitats. It was also noted that although significant effort was made to source spatial information, not all available sources had been incorporated into the Conservation Status assessment (NPWS, 2013a, b). In the years following this, significant effort was made to address these data gaps; extensive offshore reef surveys were carried out, utilising a remotely operated submersible vessel (ROV) deployed from a research vessel. Video and imagery was collected along defined transects, with a total of 100 dive sites visited (Ross *et al.,* 2018; O'Sullivan *et al.,* 2018). This, along with other data collection efforts, resulted in an increase in data available on the range of offshore reef habitat, particularly for the area between the nearshore to 200 depth contour, as noted in the 2019 Article 17 third assessment (NPWS, 2019a). It is also noted however, that the majority of the data from the surveys remained unanalysed at the time of publication (NPWS, 2019a).

1.2 Aims and Objectives

The main aim of this project was to increase the knowledge base for the national assessment of offshore reef, as required under Article 17 of the Habitats Directive.

The overarching objective of the project was to compile a desk-study report on the distribution, ecological requirements, and resilience of offshore geogenic and biogenic cold-water coral reef habitat in the Irish offshore waters greater than 200 m in depth. This desk-study report contributed towards the 2019 Habitats Directive Article 17 reporting (NPWS, 2019a, b) for offshore reef habitats and was broadly formatted to align with elements of the assessment of Conservation Status.

2 Distribution, ecology and biodiversity of geogenic and biogenic reefs

2.1 Overview

Deep cold-water corals are structurally complex sessile organisms that can form extensive biogenic reef structures that provide habitat and refuge for a diverse array of associated species (Freiwald *et al*., 2004; Roberts *et al*., 2006). Globally, cold-water corals have been typically recorded along continental shelves and margins (Davies *et al*., 2008; Roberts *et al*., 2009).

Most research on offshore reef has focused on hermatypic cold-water coral species of the Order Scleractinia (hard/stony coral) (for review see Roberts *et al*., 2009), and in particular *Lophelia pertusa*, recently re-described as *Desmophyllum dianthus* (Addamo *et al*., 2016). However, cold-water corals are extremely diverse and not simply confined to Scleractinia, but include species of the Orders Antipatharia (black coral) and Alcyonacea (soft/leather corals, gorgonians) (Cairns, 2007; Roberts *et al*., 2009).

Deep-water geogenic reefs provide substrate for colonisation by coral species which in Irish waters are mostly from submarine canyons, where the steep topology provides vertical or near vertical walls and exposed bedrock and drop stones where the incline is less steep, but still much greater than in non-canyon areas (Johnson *et al*., 2013).

Both biogenic and geogenic reef support diverse assemblages of non-coral sessile epifauna (organisms such as bryozoans, tunicates, anemones and sponges that live on the surface of organisms and/or non-living aquatic surfaces) and mobile faunal communities dominated by echinoderms, crustaceans and fish (NPWS, 2013a, b).

2.2 Key cold-water coral taxa

The main cold-water coral species belong to three cnidarian taxa: Scleractinia (hard/stony corals), Antipatharia (black corals) and Alcyonacea (soft/leather corals, gorgonians) (Cairns, 2007; Roberts *et al*., 2009) (Table 1). Biogenic reef occurs as three distinct bed-forms: small stands of coral, extensive reef structures, and coral carbonate mounds; the latter being formed by multiple generations of reef stacked upon the other. *Lophelia pertusa* (Scleractinia) is a common and widespread cold-water coral species in Irish offshore waters. This species often dominates reef structures while secondary reef-forming species include members of the Scleractinian genera *Madrepora*, *Desmophyllum* and *Solenosmilia* (NPWS, 2013a, b; Roberts *et al*., 2006, 2009; Rogers, 1999; Tyler & Zibrowius, 1992). Reef structures often support an array of Antipatharia species including *Cirrhipathes* spp., *Leiopathes* spp., *Parantipathes* spp., *Stichopathes gravieri*, and Octocorallia (soft) coral species, including *Anthomastus grandiflorus*, *Paragorgia arborea*, *Paramuricea* spp., *Anthothela* spp. and Isididae bamboo corals.

Biogenic reefs are complex ecosystems that are slow-growing and susceptible to anthropogenic pressures (Davies *et al*., 2007). Potential pressures and threats to ecological structure and function of these habitats include fisheries, gas and oil exploration, and deep-sea mining.

Table 1 Classification of major cold-water reef-forming taxa in Irish offshore waters, modified from Cairns, 2007, Roberts *et al*., 2009 and the World Register of Marine Species.

Taxon
Phylum Cnidaria
Class Anthozoa
Subclass Hexacorallia
Order Scleractinia (hard coral, stony coral, true corals, star corals)
Order Antipatharia (black corals, whip corals, wire corals)
Subclass Octocorallia
Order Alcyonacea (soft corals, leather corals, bamboo corals gorgonians)
Class Hydrozoa
Family Stylasteridae (hydrocoral, lace corals)

2.3 Distribution

2.3.1 Recorded distribution

2.3.1.1 Scleractinia

Scleractinia are also called hard or stony corals in that they create a hard rigid calcium carbonate skeleton to protect the soft tissue polyps. The most significant cold-water reef-forming (or hermatypic) Scleractinia species are *Lophelia pertusa* (Linnaeus, 1758), *Madrepora oculata* (Linnaeus, 1758) and *Solenosmilia variabilis* (Roberts *et al*., 2009). While all three species have cosmopolitan global distributions, *Lophelia pertusa* is the most commonly recorded species in the literature followed by *Madrepora oculata* and finally *Solenosmilia variabilis.*

Lophelia pertusa has been recorded in the North Atlantic, Gulf of Mexico, and Mediterranean, and to a lesser extent in the Pacific and Indian Oceans (Cairns, 2007; OSPAR, 2009; Roberts *et al*., 2009; Zibrowius, 1980) (see Figure 1). *Lophelia pertusa* has been found in water depths less than 40 m along the Norwegian Atlantic to depths exceeding 3,300 m off the New England Coast (Zibrowius, 1980). In the Irish offshore *Lophelia pertusa* is generally associated with steeply sloping seabed found along the continental slope (Hall-Spencer *et al*., 2007; OSPAR, 2009, 2010).

Based on direct observational data (drop-down camera/video, ground truth/grab records *etc*.) recorded in published and online sources, the depth range of *Lophelia pertusa* in Irish offshore waters extends from approximately 130 m on the Rockall Bank to depths exceeding 3,000 m along the Atlantic continental margin (see Figure 2). It should be noted, however, that misidentification of *Solenosmilia* as *Lophelia pertusa* may have led to the latter species being perceived to have a deeper distribution than it actually has (*e.g*., Henry & Roberts, 2013). *Lophelia pertusa* forms bush-like colonies (see Figure 3) that can measure several metres across (Roberts *et al*., 2009) and while colonies are generally white in colour, orange, yellow and red colour morphs do occur (see Figure 4) (OSPAR, 2009; Roberts *et al*., 2009).

Madrepora oculata is widely distributed in the Atlantic and Pacific Oceans (see Figure 5) and is commonly found in association with *Lophelia pertusa* (Roberts *et al*., 2009). Live *Madrepora oculata* has been recorded at depths ranging from 55 m off Brazil to almost 2,000 m south of the Reykjanes Ridge (Zibrowius, 1980).

Figure 6 shows the distribution of *Madrepora oculata* in Irish offshore waters based on direct observations recorded in published and online sources. *Madrepora oculata* reef structure (see

Figure 7) is more fragile than that of *Lophelia pertusa*, and does not occur as extensive frameworks where the latter dominates.

Solensomilia variabilis is a hermatypic coral that is widely distributed in the Atlantic Ocean and South Pacific, and has yet to be observed in the Antarctic or in the North or East Pacific. Globally it is found at depths ranging between 220 m and 2,165 m and commonly found in association with *Lophelia pertusa* and *Madrepora oculata*. Figure 8 shows the global distribution of *Solenosmilia variabilis* in Irish offshore waters, based on direct observation data (Roberts *et al*., 2009).

In Irish waters, *Solenosmilia variabilis* is generally found at depths of 1,000 m to 1,300 m along the Porcupine and Rockall Bank margins, often appearing as coral rubble (Grehan, pers. comm.). However, it was recently identified at depths previously unrecorded (>1600m) during surveys within the Porcupine Shelf candidate SAC (NPWS, 2023a). *Solenosmilia variabilis* grows into small bushy colonies with the dichotomous branches often joining together. *Solenosmilia variabilis* grows from an encrusting base on which there are a few corallites. The branches are thick near the base of the colony but more slender above; sometimes upper branches are just 3 mm to 5 mm in diameter. The species is a long-lived species with a growth rate of about 1 mm/year (Fallon *et al*., 2013) and is adversely affected by ocean acidification, climate change and trawling.

A total of eight offshore SACs have been designated for the protection of biogenic and/or geogenic reef habitat in Irish offshore waters. The distribution of six of these offshore SACs is illustrated in Figure 9, with the newly designated candidate SACs (Southern Canyons SAC and Porcupine Shelf SAC) not included. The Scleractinian species *Lophelia pertusa* and *Madrepora oculata* are the major reef-forming species of the Belgica Mound Province SAC (NPWS, 2024a) and North-west Porcupine Bank SAC (NPWS, 2014a), and are found to form patch reefs in the Hovland Mound Province SAC (NPWS, 2014b) and the Porcupine Shelf cSAC (NPWS, 2023a). Occasional clumps of *Madrepora oculata* and *Desmophyllum* occur within the Southern Canyons cSAC (NPWS, 2023b). *Lophelia pertusa* has been identified as the major framework species at the South-west Porcupine Bank SAC (NPWS, 2024b) while *Solenosmilia variabilis* has been identified at the South-east Rockall Bank SAC (NPWS, 2014c) and the Porcupine Shelf cSAC (NPWS, 2023a).

2.3.1.2 Antipatharia

Antipatharia are commonly named black corals, for their distinctive dark coloured skeletons, which support living tissue that can vary widely in colour across species (Roberts *et al*., 2009). Antipatharia coral form unbranched whips and bush-like colonies (see Figure 10) which can reach up to 3 m in height. Black coral are ubiquitous in the deep waters of the world's oceans, with some species recorded at depths exceeding 8,000 m.

Based on published direct observations, black coral have been recorded on the Rockall Bank, along the Atlantic continental slope margin and in the canyon complexes to the south of the Porcupine Basin and Goban Spur (see Figure 11). Black coral species found in Irish offshore waters include *Parantipathes hirondelle*, *Trissopathes* spp., *Bathypathes* spp., *Leiopathes expansa*, *Antipathese dichotoma*, *Stichopathes gravieri*, *Stauropathes punctate*, *Telopathes magna*, *Cirrhipathes* spp., *Parantipathes* spp. and *Stichopathes gravieri* (Allcock *et al*., 2016; OSPAR, 2010). Black coral are listed as important community characterising species at the South-east Rockall Bank SAC (NPWS, 2014c) and Porcupine Bank Canyon SAC (NPWS, 2024c) (Figure 9).

2.3.1.3 Alcyonacea

Reef-forming deep-water species of the subclass Octocorallia are ubiquitous in the world's oceans extending from the Antarctic to the Arctic Circle and have been recorded in relatively shallow waters less than 100 m to depths exceeding 6,600 m (Roberts *et al*., 2009). Reef colonies can measure metres across, providing habitat for an array of invertebrate and fish species. Within the subclass Octocorallia deep-water species of the order Alcyonacea are often referred to as sea whips (*e.g*. *Paramuricea* spp.) on account of their ability to flex and bend in response to local water currents, while some species are named bamboo coral (family Isididae) after their short flexible skeleton nodes that connect to form structures resembling bamboo stalks.

Published direct observation data indicate that octocorals are widely distributed in the Irish offshore, extending from the Hatton Bank and Rockall Bank to the Atlantic continental slope margin and the canyon complexes to the south of the Porcupine Basin and Goban Spur (see Figure 12). Octocoral species are found at the Belgic Mound Province SAC (NPWS, 2024a), South-east Rockall Bank SAC (NPWS, 2014c), Southern Canyons SAC (NPWS, 2023b) and Porcupine Shelf SAC (NPWS, 2023a) (Figure 9).

2.3.1.4 Stylasteridae

Like the octocorals, species of the hydrozoan family Stylasteridae (or hydrocoral, lace corals) are found throughout the world's oceans extending from the Bering Sea, north of Iceland to the Antarctic. While stylasterids are predominately associated with oceanic islands, archipelagos and seamounts (Roberts *et al*., 2006, 2009), stylasterid colonies have been recorded in the Belgic Mound Province SAC (NPWS, 2024a), Hovland Mound Province SAC (NPWS, 2014b), South-east Rockall Bank SAC (NPWS, 2014c) and Porcupine Bank Canyon SAC (NPWS, 2024c) (see Figure 9).

2.3.1.5 Carbonate mounds

Coral carbonate mounds are distinct features that are formed over timescales of one to two million years by successive periods of growth, erosion and sedimentation of reef-forming corals, including the Scleractinian species *Lophelia pertusa* and *Madrepora oculata* (De Mol *et al*., 2002; Hovland *et al*., 1998; Kano *et al*., 2007; OSPAR, 2010; Roberts *et al*., 2006, 2009). Coral carbonate mounds typically comprise carbonate sands, muds and silts (Kano *et al*., 2007; OSPAR, 2010; Roberts *et al*., 2006, 2009; van Weering *et al*., 2003). Carbonate mounds supporting living coral are termed 'active' while mounds without living coral are termed 'retired' (Huvenne *et al*., 2005).

Published data in the Irish offshore indicate that coral mounds are widely distributed across the Rockall Bank and along the Atlantic Margin in water depths ranging between 500 m and 1,100 m (Kenyon *et al*., 2003; OSPAR, 2010) (see Figure 13). Wheeler *et al*. (2007) described carbonate mounds occurring in distinct regions (termed provinces) on the Irish continental margin, with the largest mounds having diameters of up to 5 km and elevations up to 350 m above the surrounding seafloor. Morphological variation between mound provinces has been attributed to the local environmental conditions under which mounds are initiated and grow.

De Mol *et al*. (2002) described carbonate mound provinces in the Porcupine Seabight, the Belgica Province, Hovland Province, and Magellan Mound Province, each defined by distinct mound characteristics. The Belgica Mound Province is located in the eastern Porcupine Seabight and is characterised by dense coral reefs on the top and upper western flanks of the mounds. The Hovland Mound Province shows similar mound morphology; however, living corals are restricted to isolated patches with present-day coral reef and mound growth poor and limited to the upper flanks (Dorschel *et al*., 2005; Rüggeberg *et al*., 2007). The Magellan Mound Province north of the Hovland Mound Province consists mainly of buried mounds (Huvenne *et al*., 2007). Carbonate mounds on the western Rockall Bank and the northern Porcupine Bank occur in water depths between 550 m and 1,200 m. Living cold-water corals are found at depths of 600 m to 800 m. They form a complex arrangement of mound clusters that are aligned up- and down-slope (Mienis *et al*., 2006). The mounds have diameters of hundreds of meters to several kilometres.

The Arc Mound Province, situated on the south-western margin of the Porcupine Bank, is comprised of over 40 carbonate build-ups, measuring up to a few hundred metres in length and up to 50 m in height, aligned along scarps in water depths of between 630 m and 850 m (Stapleton *et al*., 2013) (see Figure 14). A number of the carbonate mounds in the region have been shown to support extensive colonies of *Lophelia pertusa* (see Figure 15).

Carbonate mounds are listed as significant features of the Belgica Mound Province SAC (NPWS, 2024a), the North-west Porcupine Bank SAC (NPWS, 2014a), the Hovland Mound Province SAC (NPWS, 2014c) and the South-west Porcupine Bank SAC (NPWS, 2024b). The location of these SAC sites is shown in Figure 9.

An extensive area of mini-mounds, called the Macnas Mounds, with diameters of 50 m to 100 m rising to about 5 m in height, has been recorded along the continental slope on the eastern flank of the Porcupine Seabight, in water depths from 300 m to 500 m (Wilson *et al*., 2007) (see Figure 16). The mounds are of particular interest in terms of benthic habitat, providing spawning ground for Hake *Merluccius merluccius* and the area is known by fisherman as the ‘Coral Ground’. Video observations conducted at the Macnas Mounds have revealed that the mounds are covered in coral, albeit rubble, thus qualifying as biogenic coral carbonate habitat.

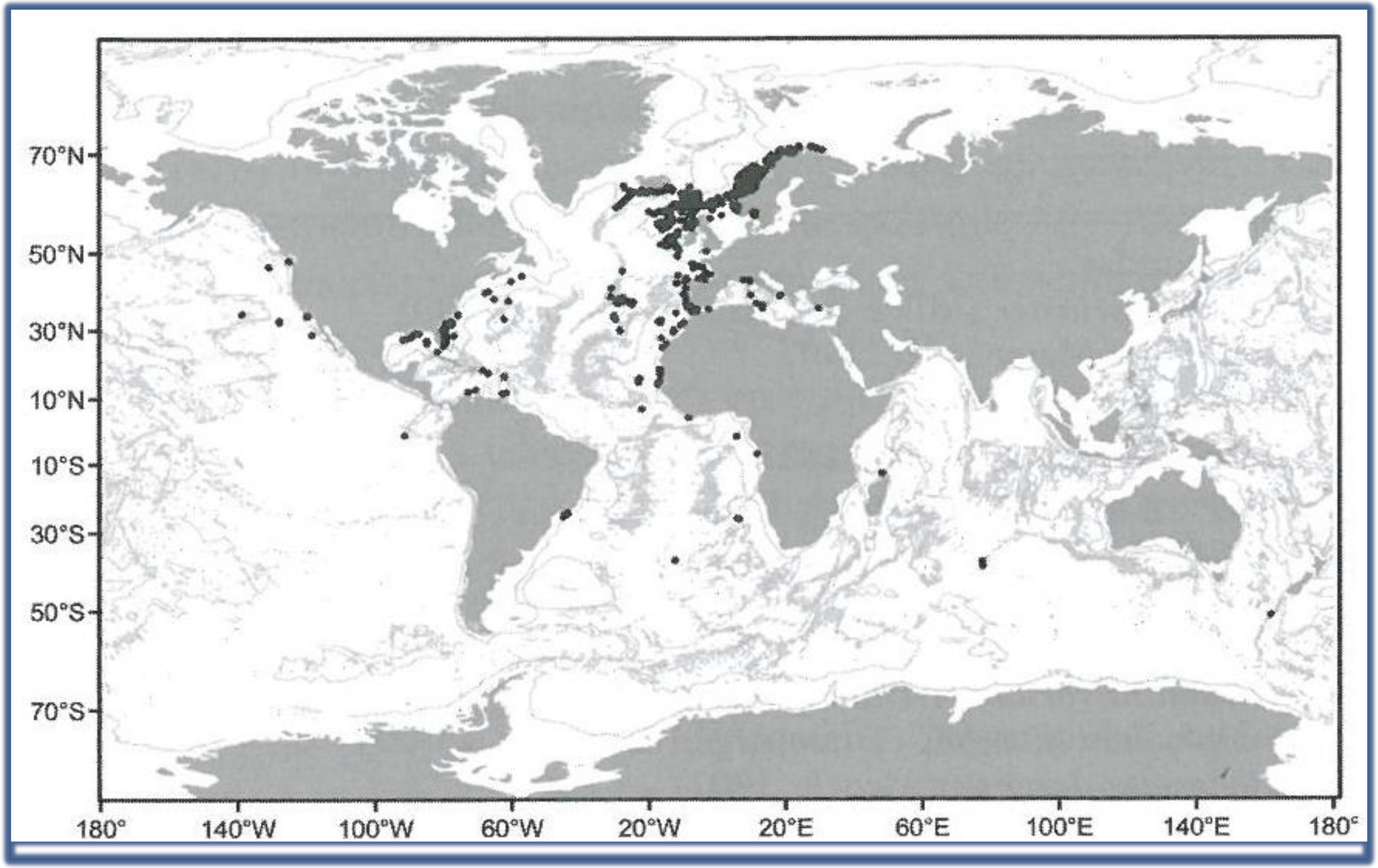


Figure 1 Map showing the global distribution of *Lophelia pertusa* (●) (from Roberts *et al*., 2009) (isobaths at 2,000 m, 5,000 m and 9,000 m)

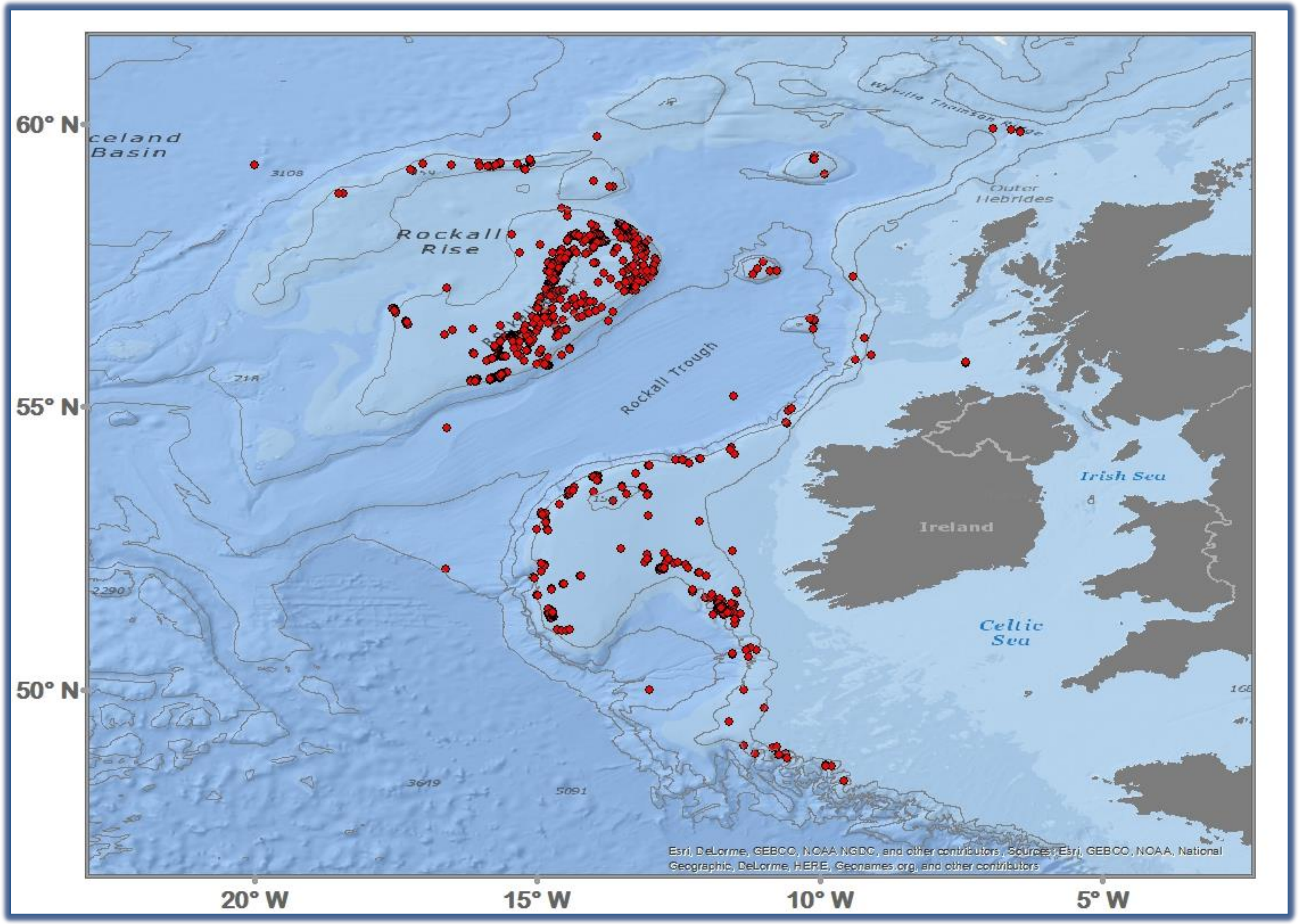


Figure 2 Map showing the distribution of *Lophelia pertusa* (●) in Irish offshore waters based on direct observations recorded in published and online sources. Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

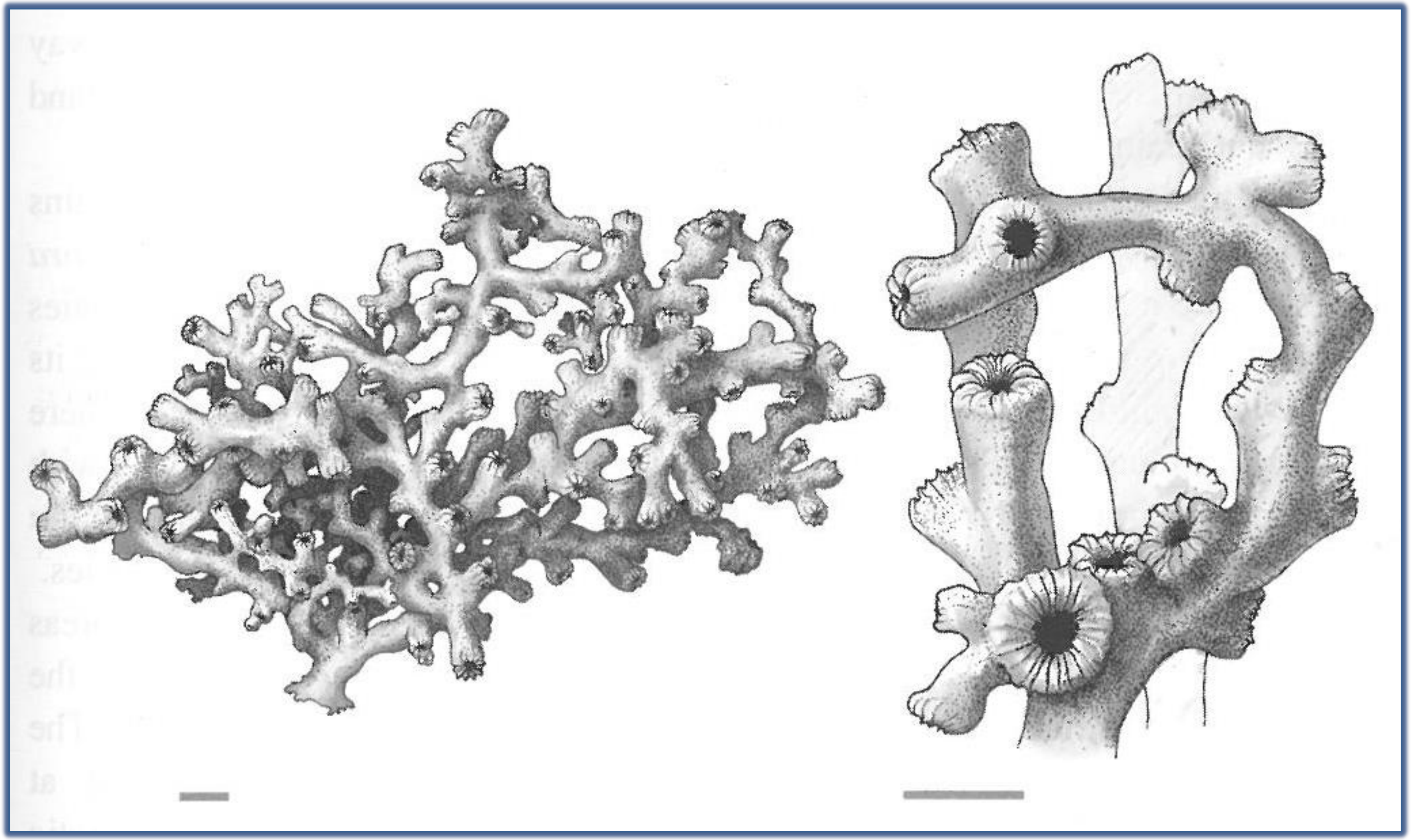


Figure 3 Drawing of *Lophelia pertusa* skeleton showing framework formed by the coral colony and details of individual polyps (from Roberts *et al*., 2009). Scale bars 10 mm (colony) and 10 mm (polyp detail).

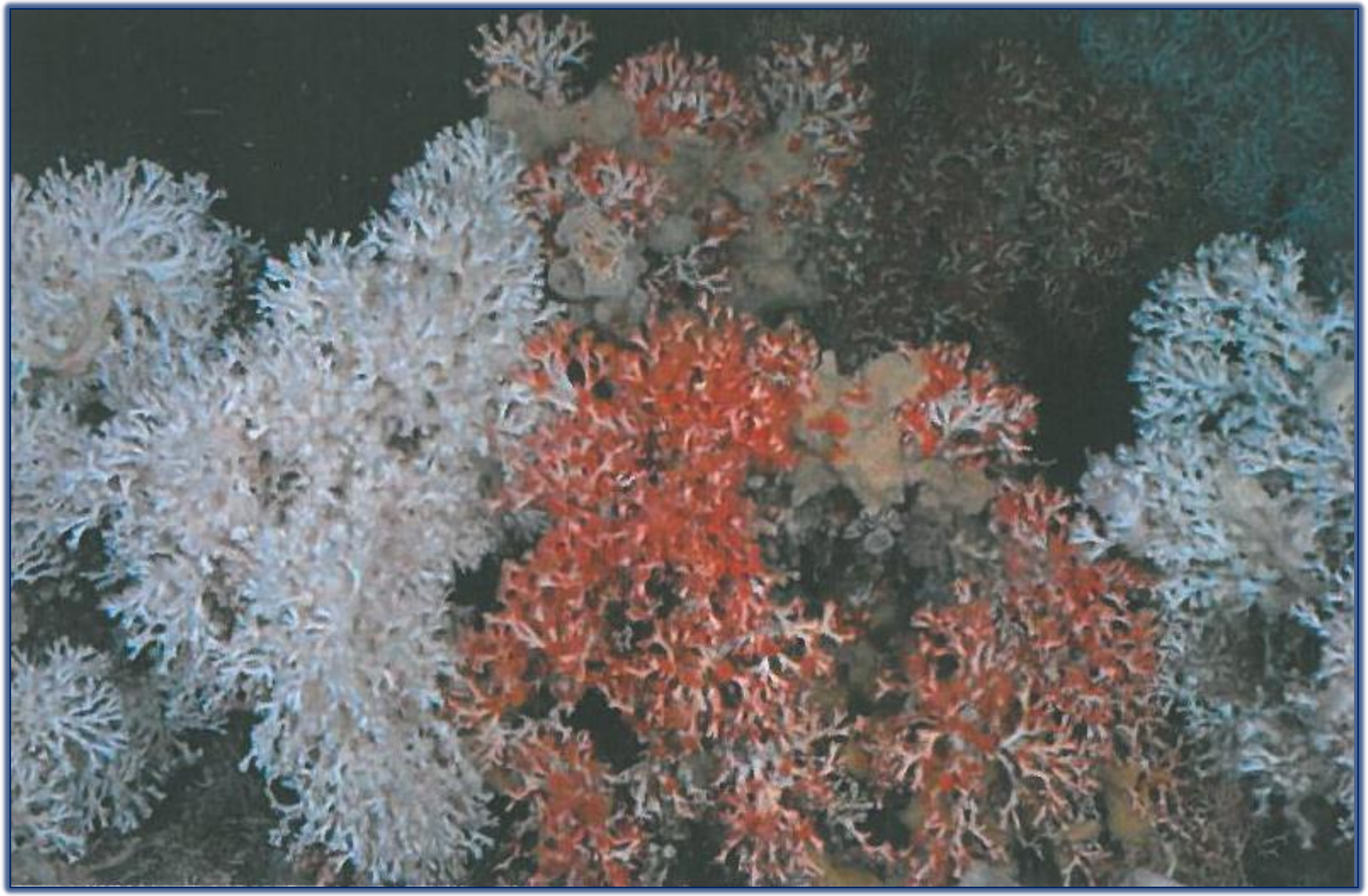


Figure 4 *Lophelia pertusa* reef (showing white and orange morphs) at 400 m depth off Rost, Norway (from OSPAR, 2009).

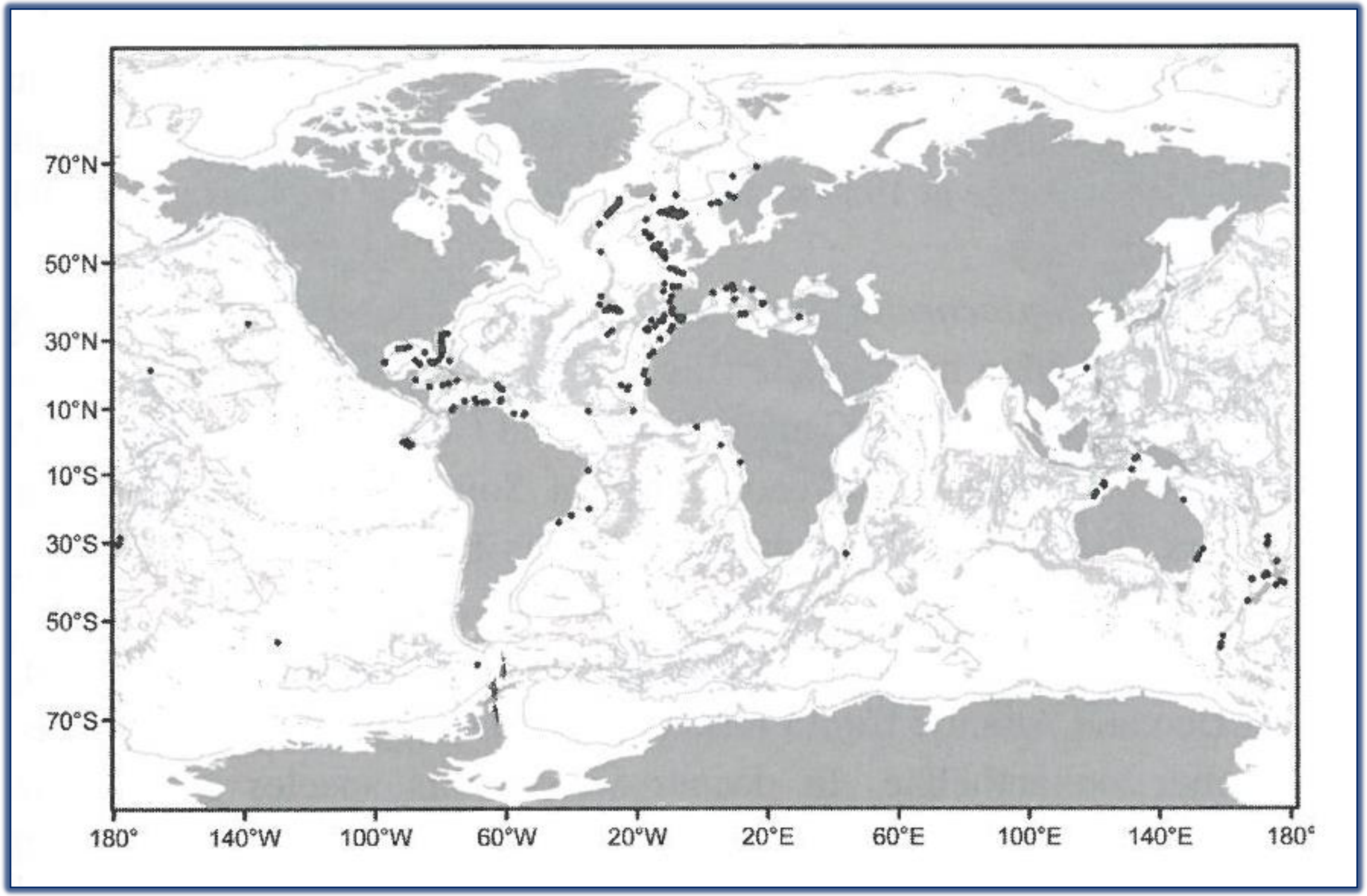


Figure 5 Map showing the global distribution of *Madrepora oculata* (●) (from Roberts *et al*., 2009) (isobaths at 2,000 m, 5,000 m and 9,000 m).

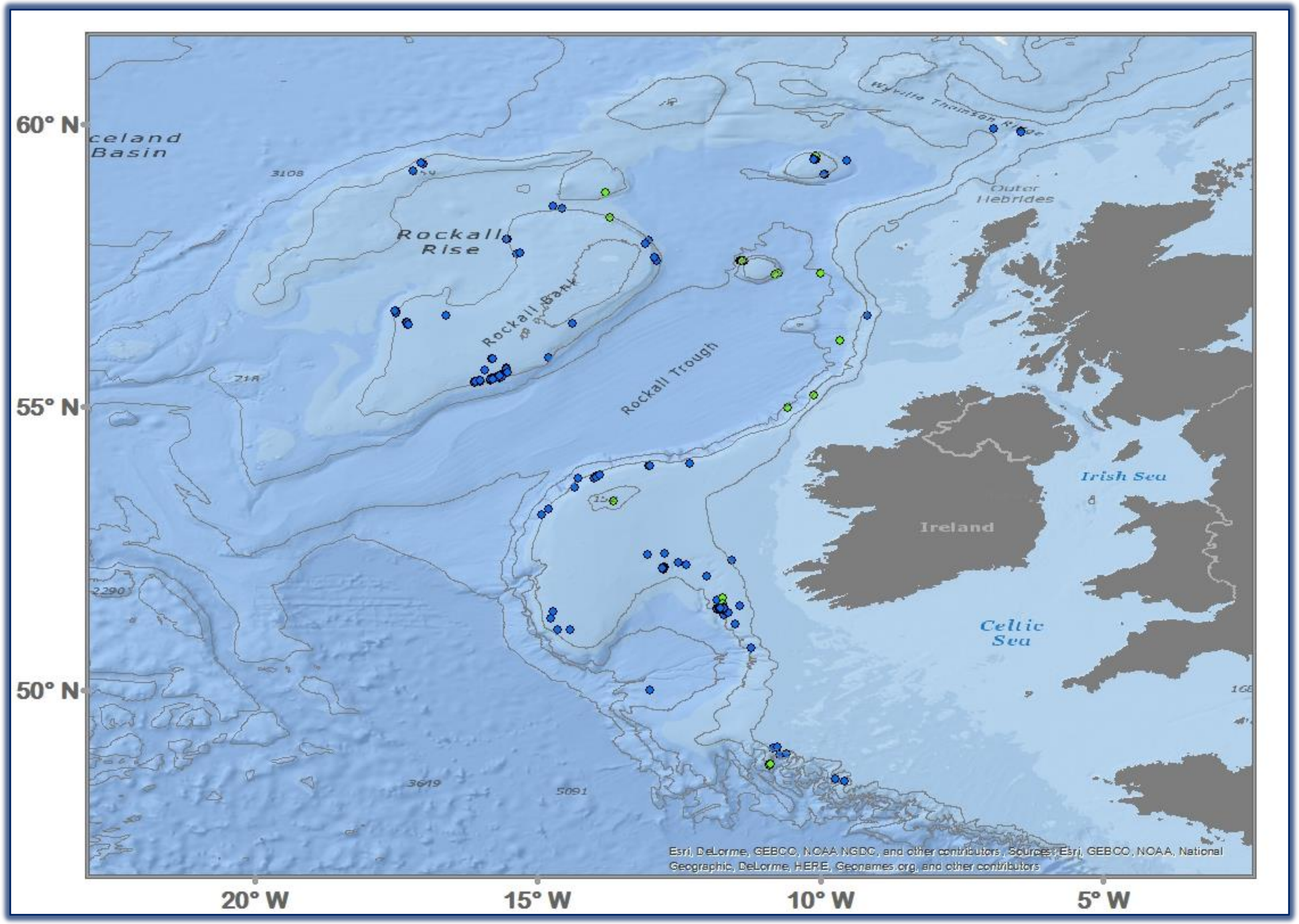


Figure 6 Map showing the distribution of *Madrepora oculata* (●) and *Solenosmilia variabilis* (●) in Irish offshore waters based on direct observations recorded in published and online sources. Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

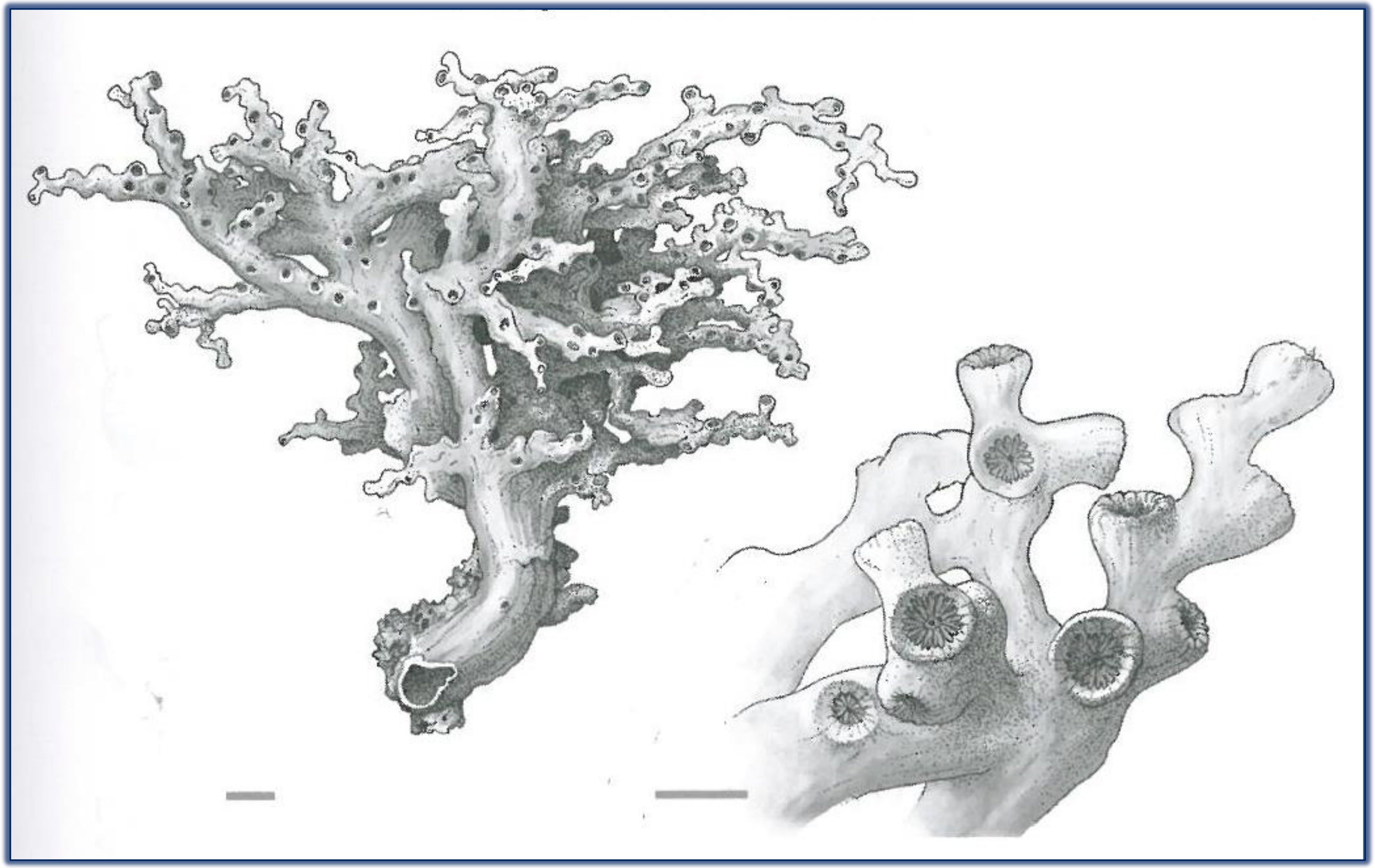


Figure 7 Drawing of *Madrepora oculata* skeleton showing framework formed by the coral colony and details of individual polyps (from Roberts *et al*., 2009). Scale bars: 10 mm (colony) and 4 mm (polyp detail).

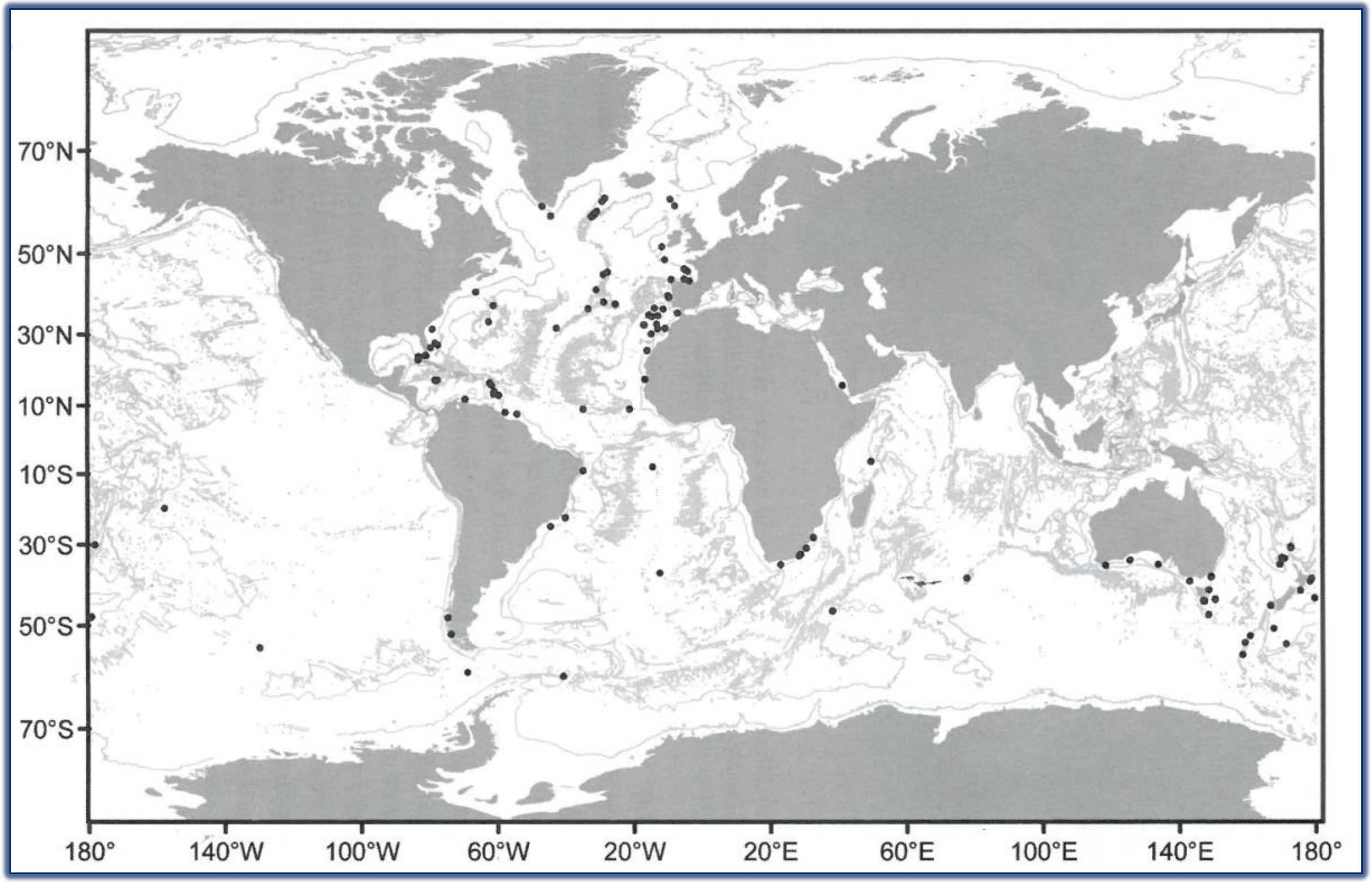
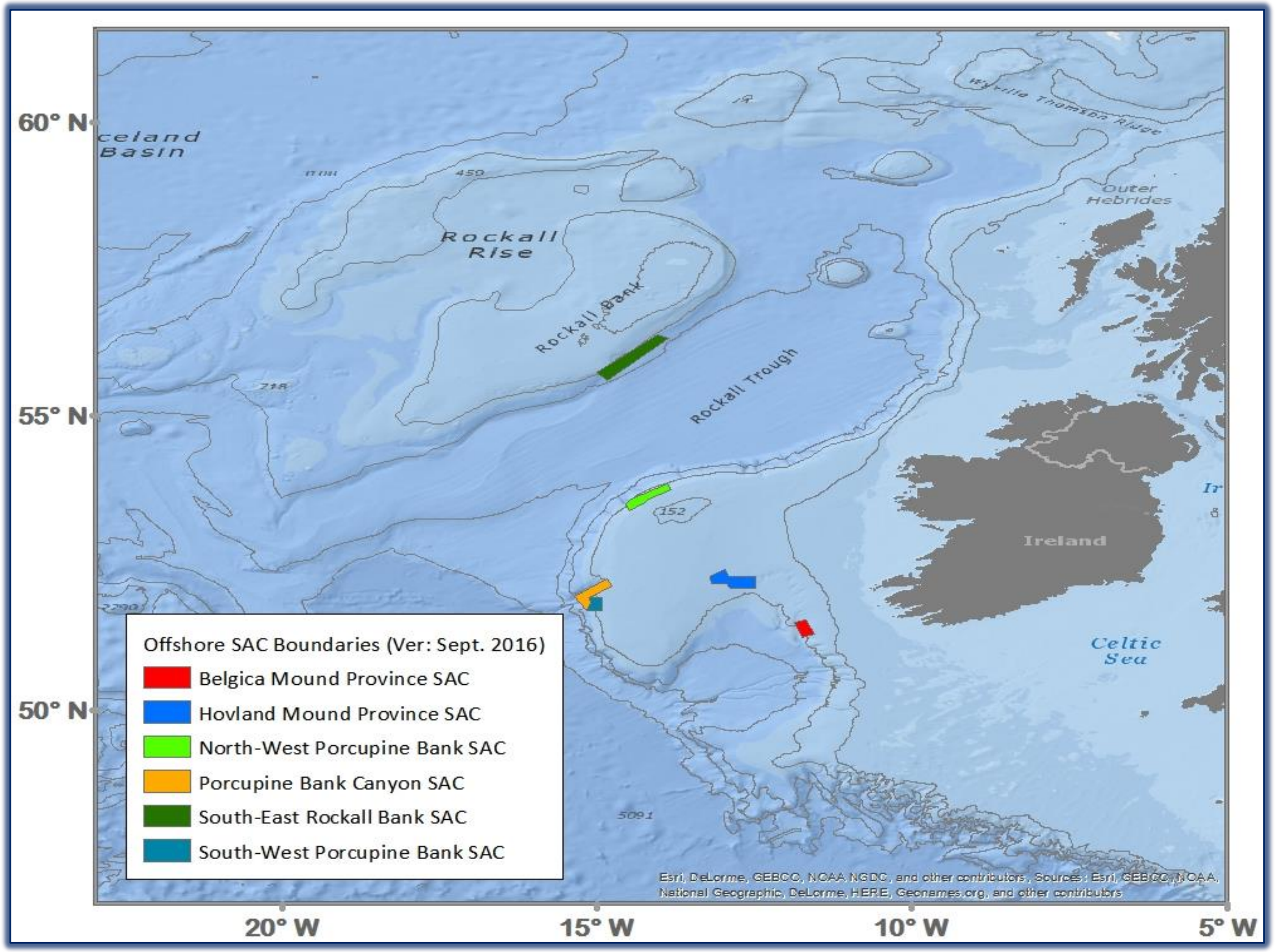


Figure 8 Map showing the global distribution of *Solenosmilia variabilis* (●) (from Roberts *et al*., 2009) (isobaths at 2,000 m, 5,000 m and 9,000 m).



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 9 Offshore Special Areas of Conservation in Irish offshore waters. Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

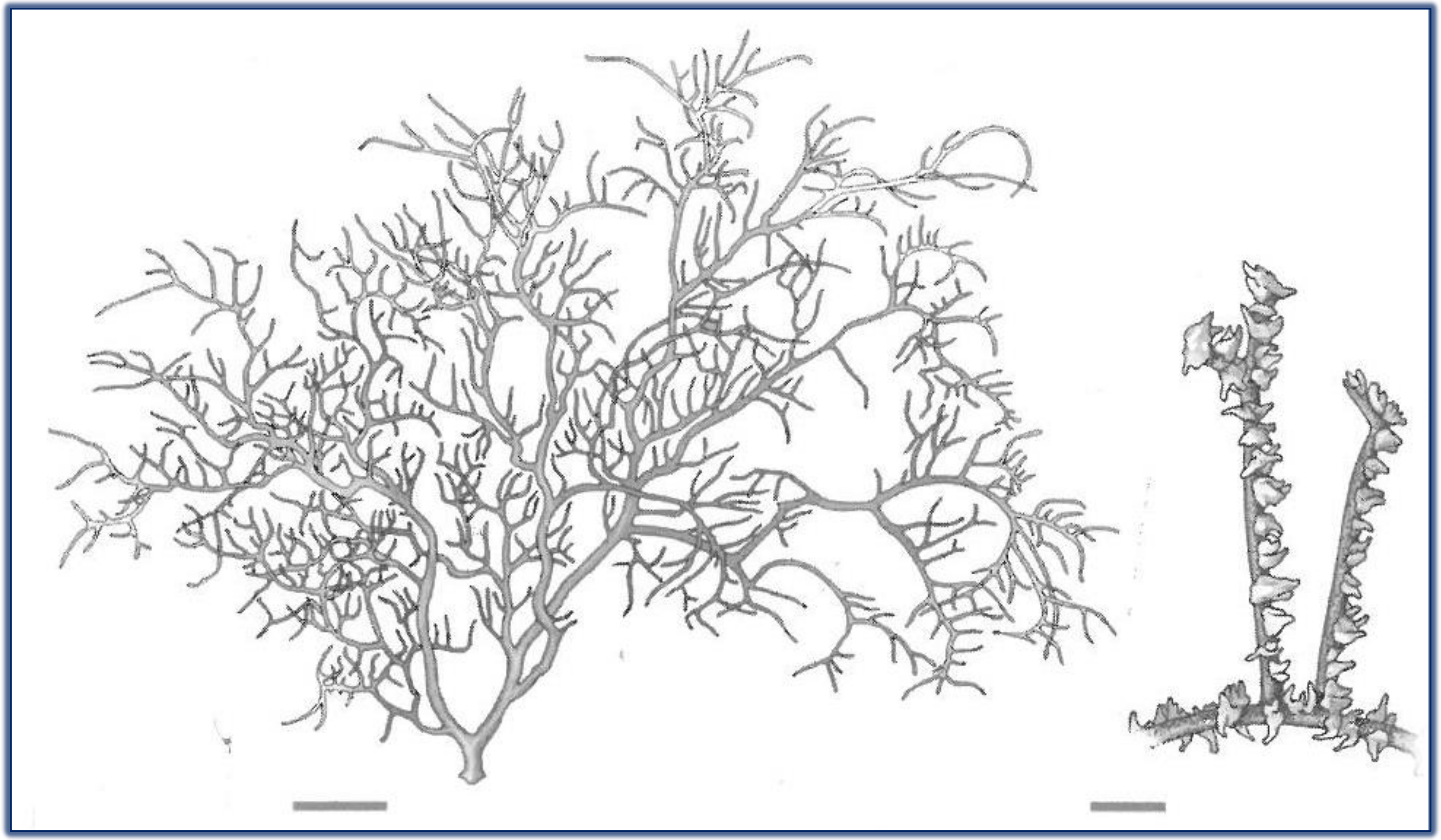


Figure 10 Drawing of a colony of the Antipatharia coral species *Leiopathes spp.* showing framework formed by the coral colony and details of individual polyps (from Roberts *et al.,* 2009). Scale bars: 50 mm (colony) and 3 mm (polyps detail).

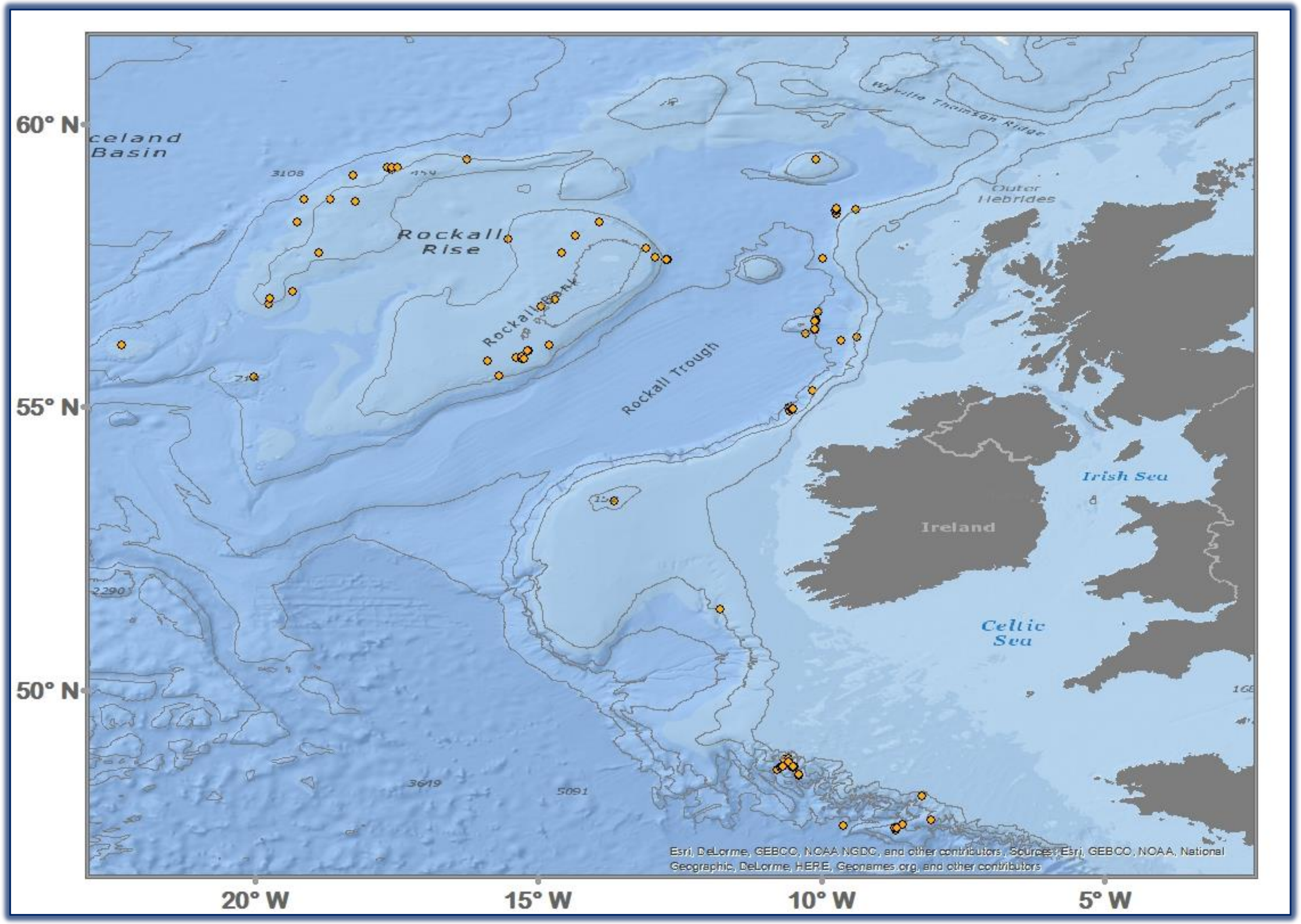


Figure 11 Map showing the distribution of Antipatharia (black corals) (●) in Irish offshore waters based on direct observations recorded in published and online sources. Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

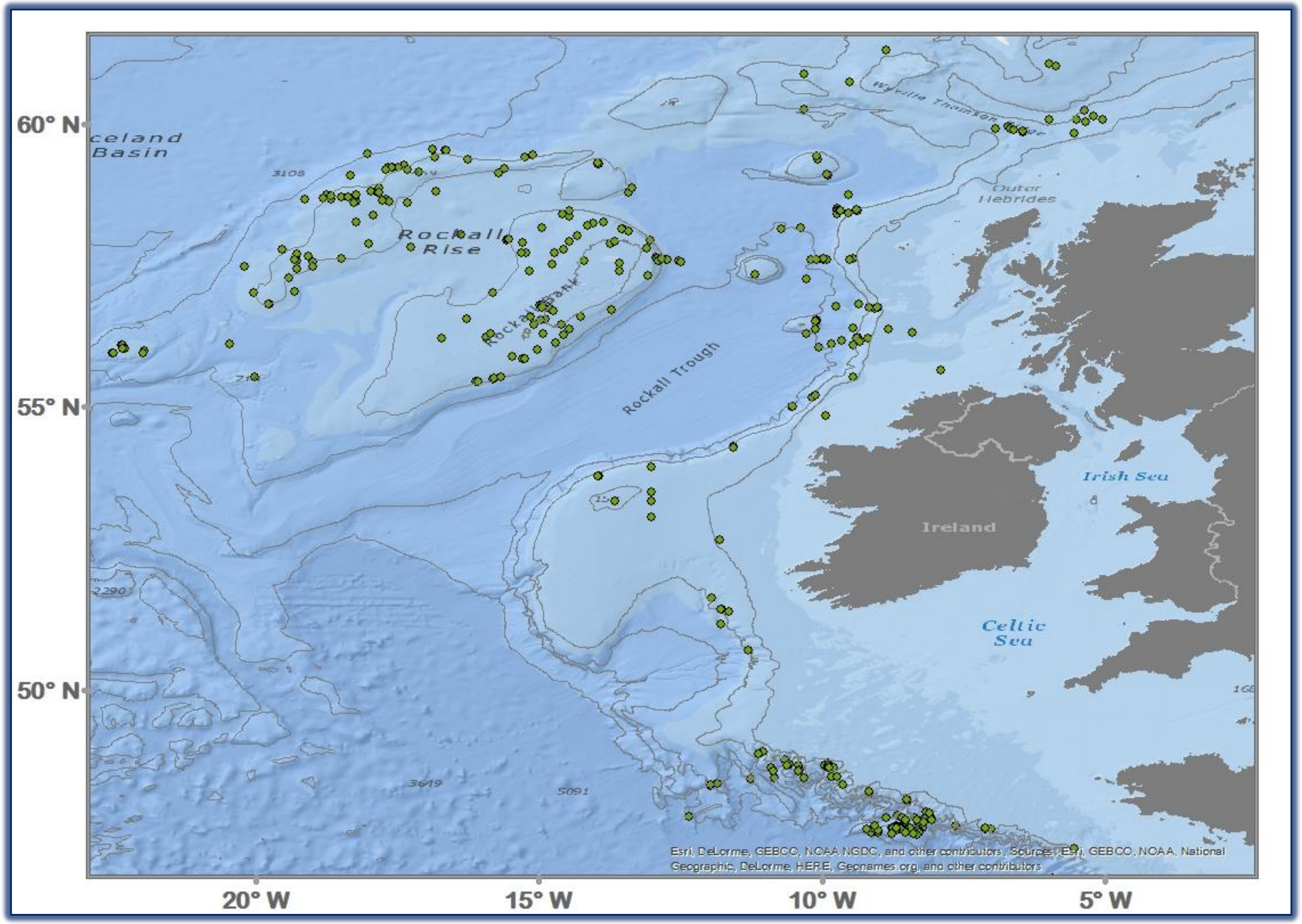
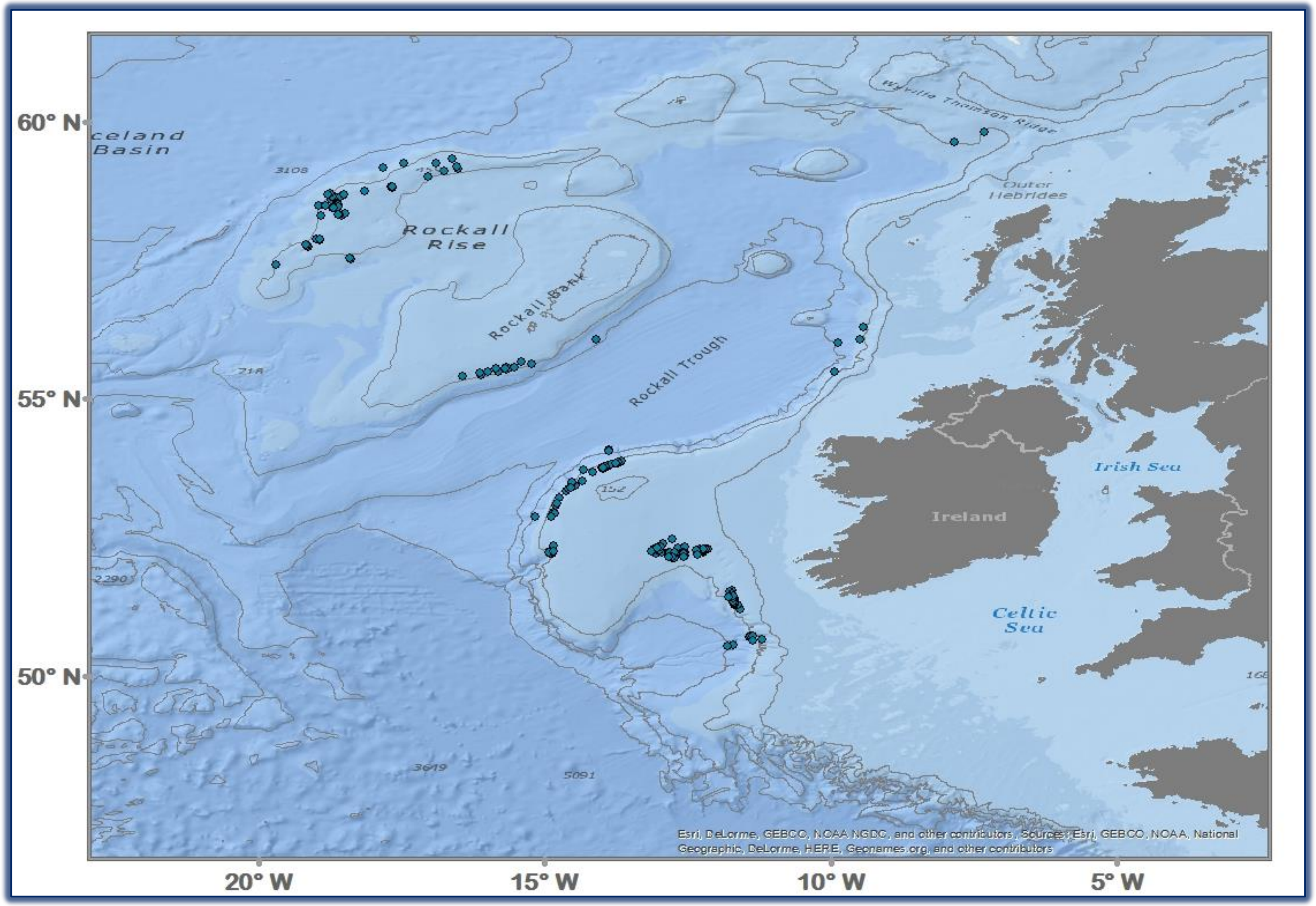


Figure 12 Map showing the distribution of Octocorallia (soft corals) (●) in Irish offshore waters based on observations recorded in published and online sources. The isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m bathymetry contours are shown.



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 13 Map showing the distribution of carbonate mounds (●) in Irish offshore waters based on observations recorded in published and online sources. Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

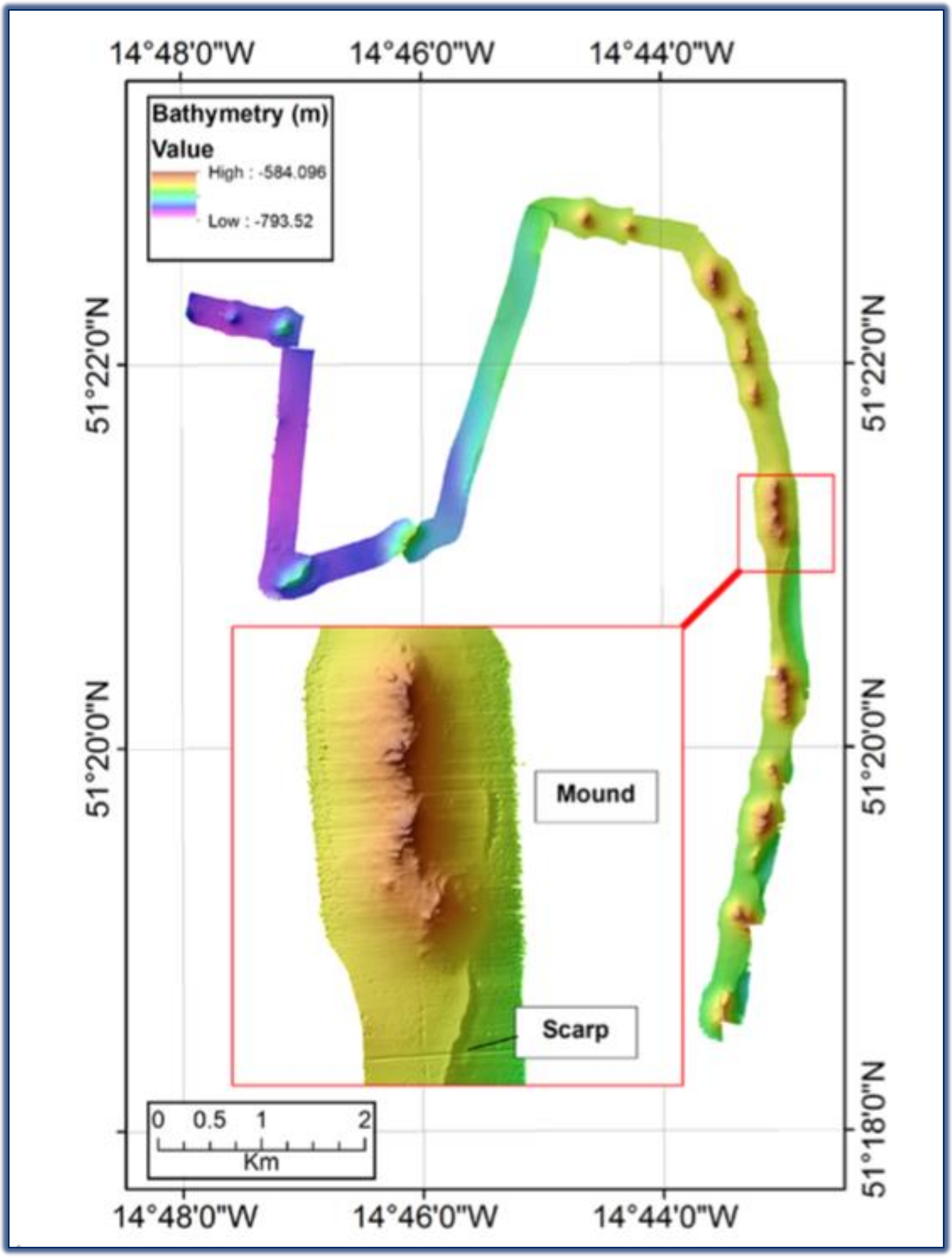


Figure 14 Multibeam bathymetry showing carbonate mounds and associated scarp features (from Stapleton *et al*., 2013).

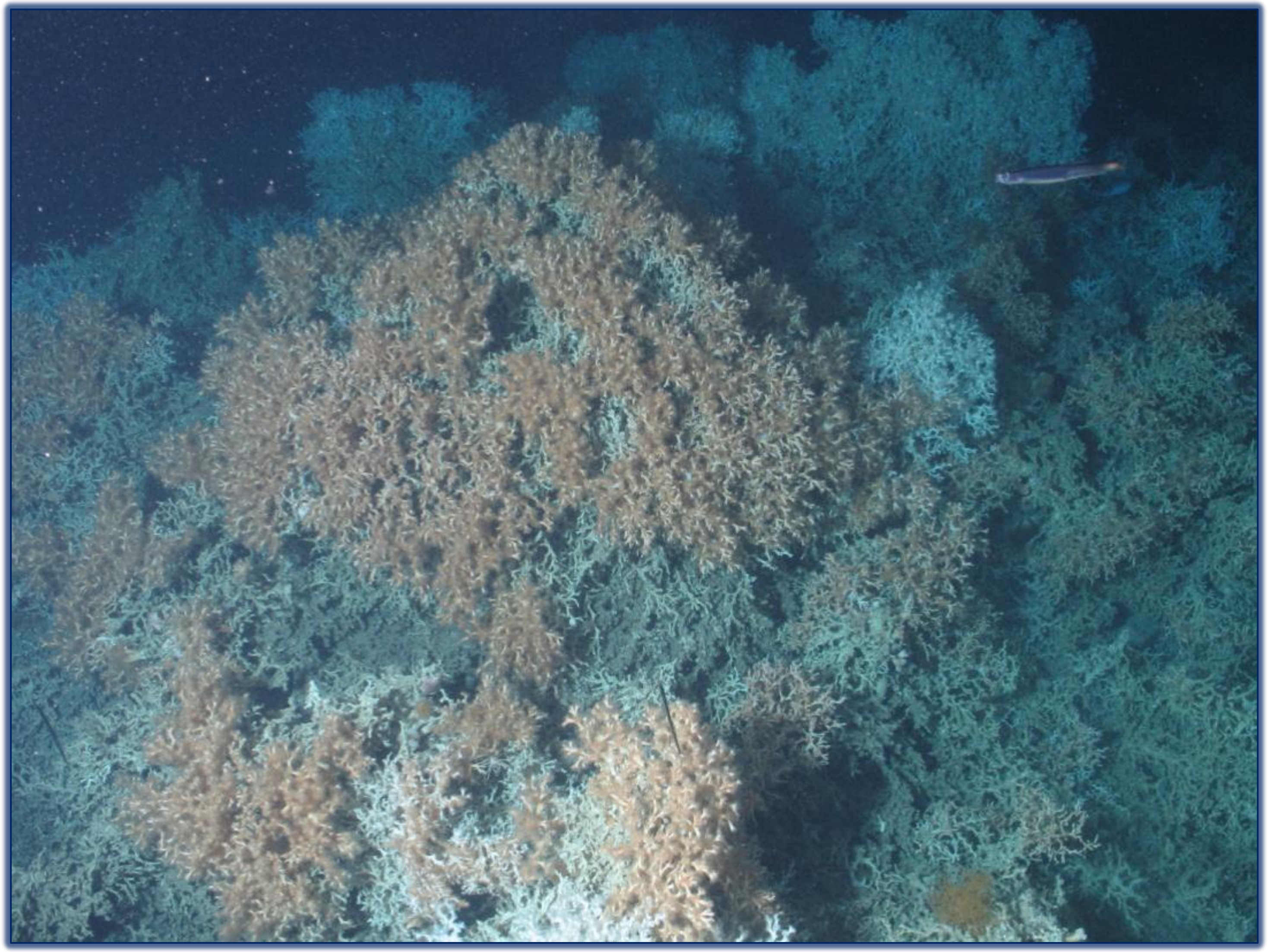


Figure 15 Coral mounds in the Arc Province supporting *Lophelia pertusa* reefs (from Stapleton *et al*., 2013).

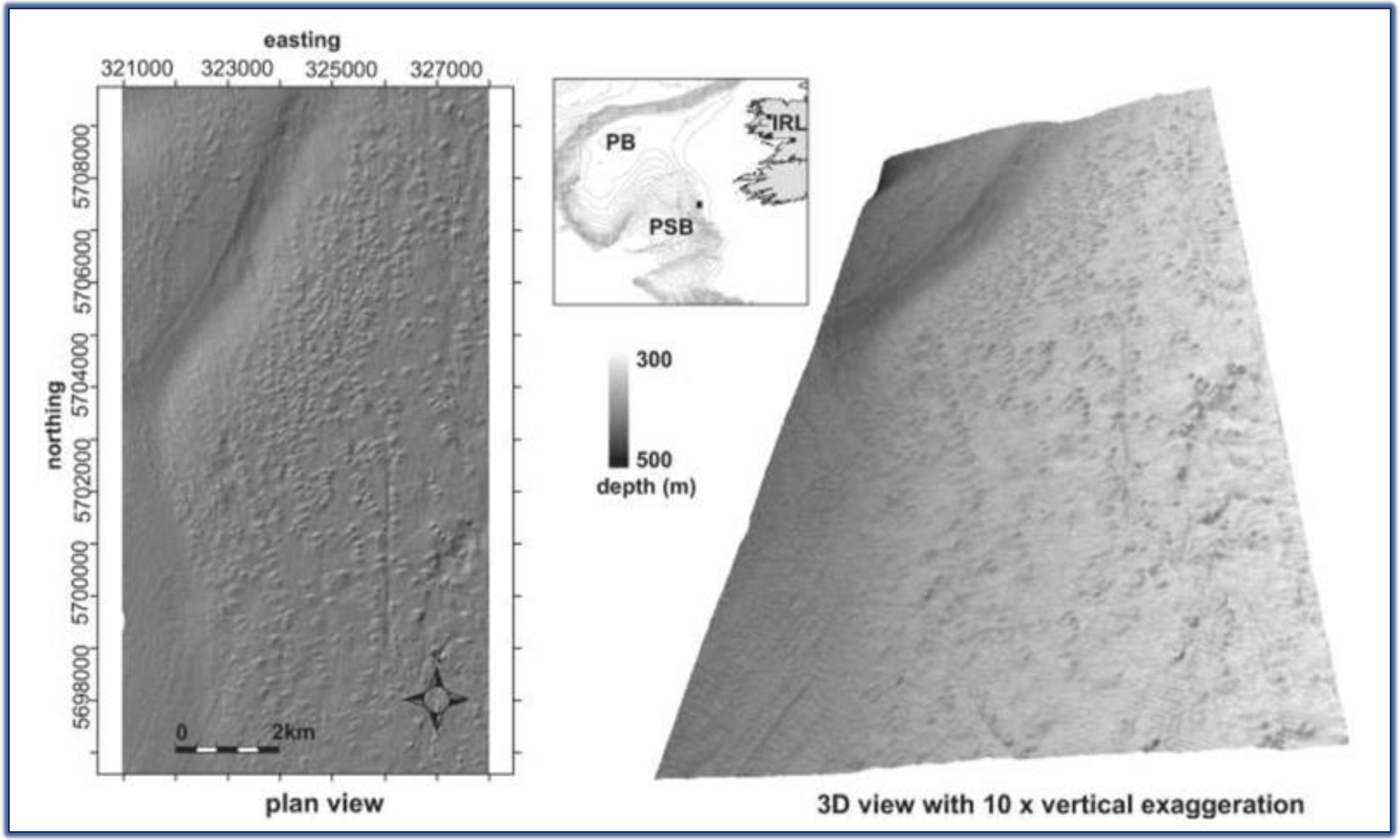


Figure 16 The Macnas Mounds in the Porcupine Seabight (from Wilson *et al.,* 2007).

2.3.2 Modelled distribution

Due to the inherent difficulty and expense associated with surveying deep-water ecosystems, knowledge of the true extent of coral distributions and the specific environmental factors controlling occurrence are poorly understood (Davies *et al*., 2008; Rengstorf *et al*., 2013; Yesson *et al*., 2012, 2015). To overcome this knowledge gap, predictive habitat modelling techniques have been used to create maps of potential distribution and to identify the ecological requirements of deep-water coral (*e.g.* Guinan *et al*., 2009; Mohn *et al*., 2014; Rengstorf *et al*., 2012, 2013; Ross & Howell, 2013; Yesson *et al*., 2012, 2015). These modelled distribution maps are useful to help develop networks of marine protected areas.

It should be noted however, that studies relying on modelling of sparse broad-scale environmental data, such as those aimed at identifying global habitat distributions, can overestimate the extent of habitat. In these circumstances, predicted distributions are not sufficiently accurate to support assessments or appropriate planning of protected areas. Consequently, it has been recommended that modelling be conducted at geographic scales appropriate to the resolution of available environmental data (Rengstorf, 2013). Figures 17, 18 and 19 show modelled distributions of some of the major coral reef taxa in Irish waters, namely Scleractinia, Antipatharia and Octocorallia. In general, habitat suitability modelling studies indicate that the most important factors influencing coral distribution include temperature, salinity, seabed slope, water currents, and dissolved oxygen.

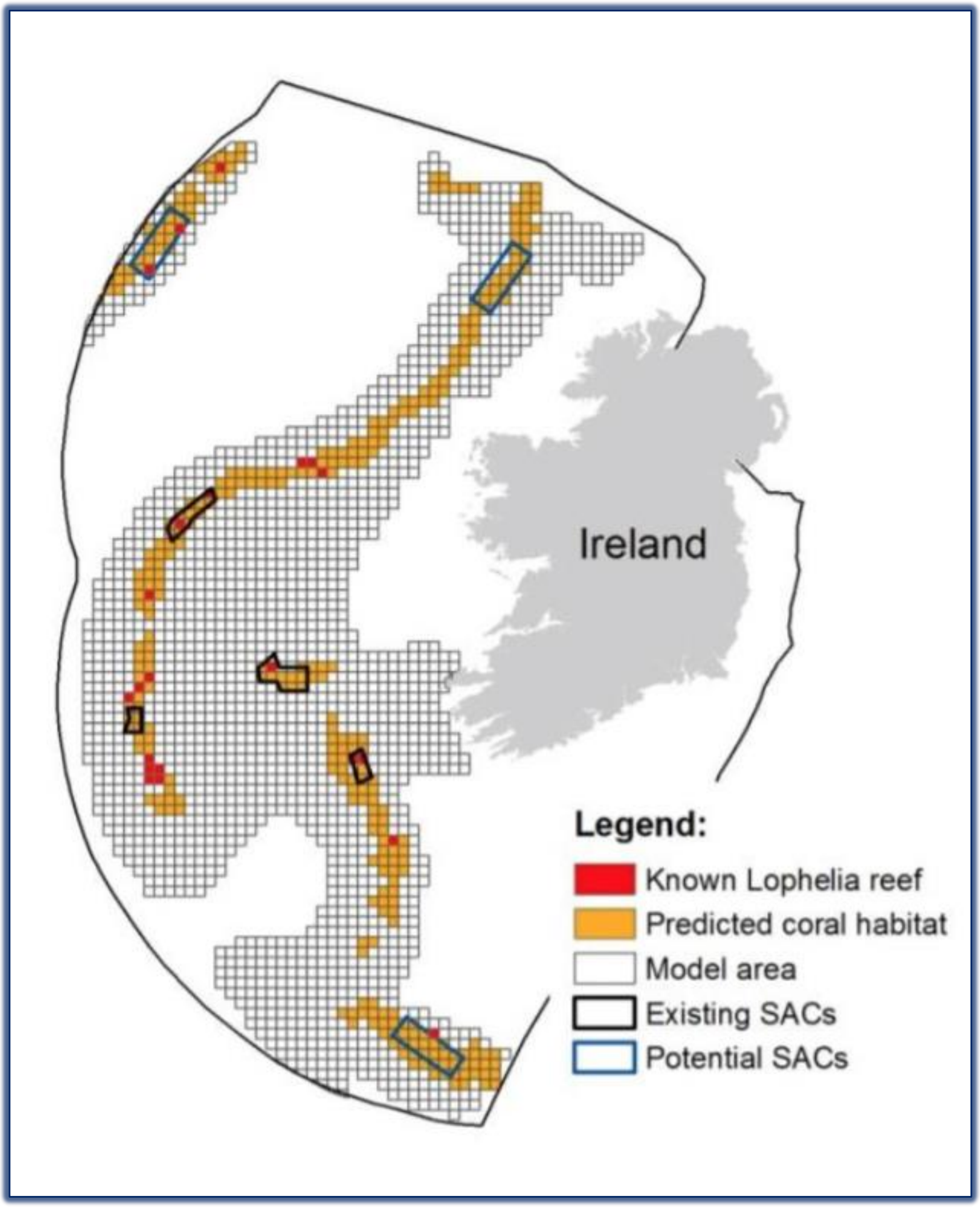


Figure 17 Habitat suitability map for *Lophelia pertusa* for Irish offshore waters. Map showing the distribution of known and predicted *Lophelia pertusa* reef habitat, as well as existing and suggested (potential) coral SACs within the Irish Exclusive Fisheries Zone (solid black line). Each grid node is 10 x 10km (from Rengstorf *et al.,* 2013).

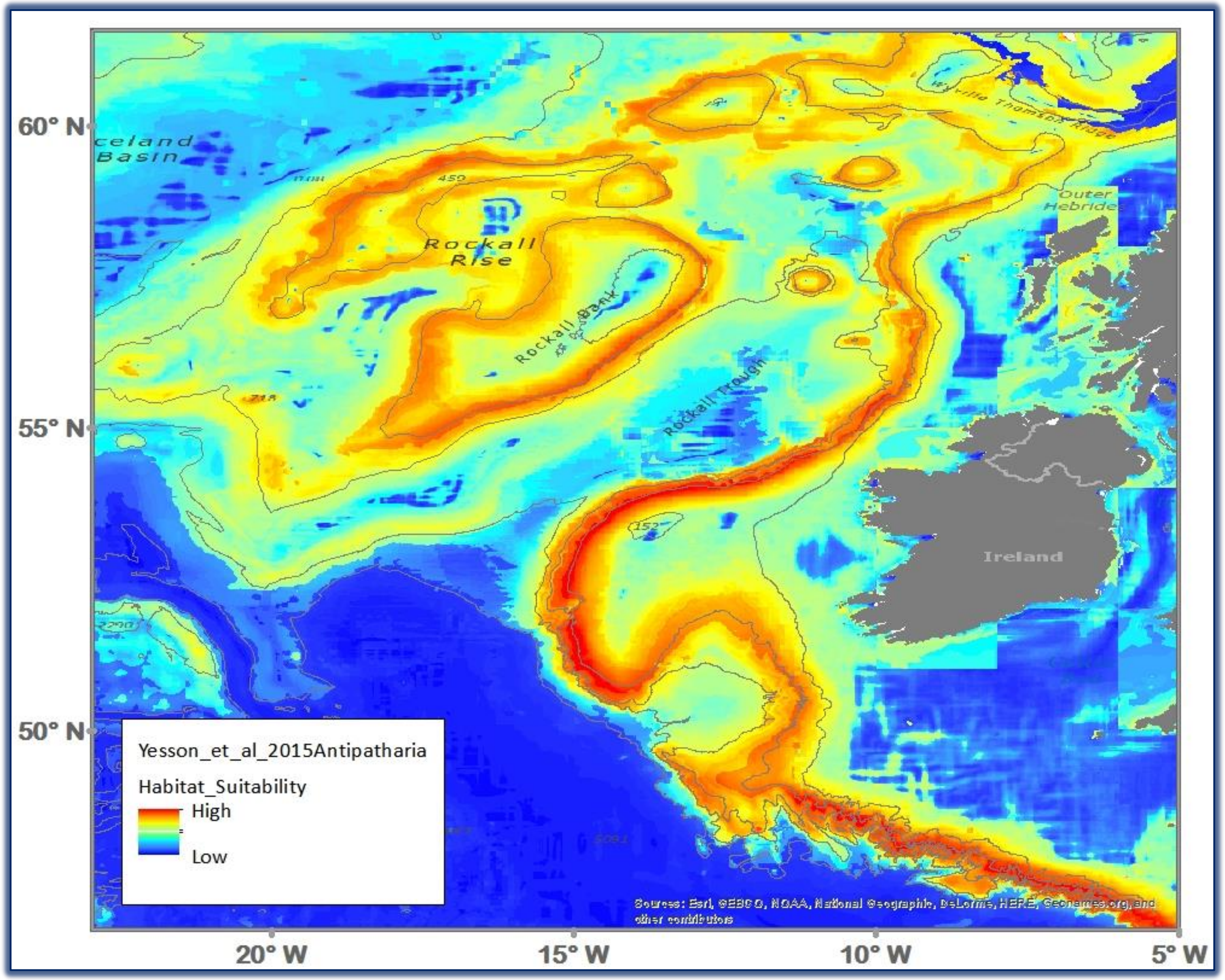


Figure 18 Habitat suitability map for Anthipatharia taxa in the Irish offshore waters (from Yesson *et al.,* 2015). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

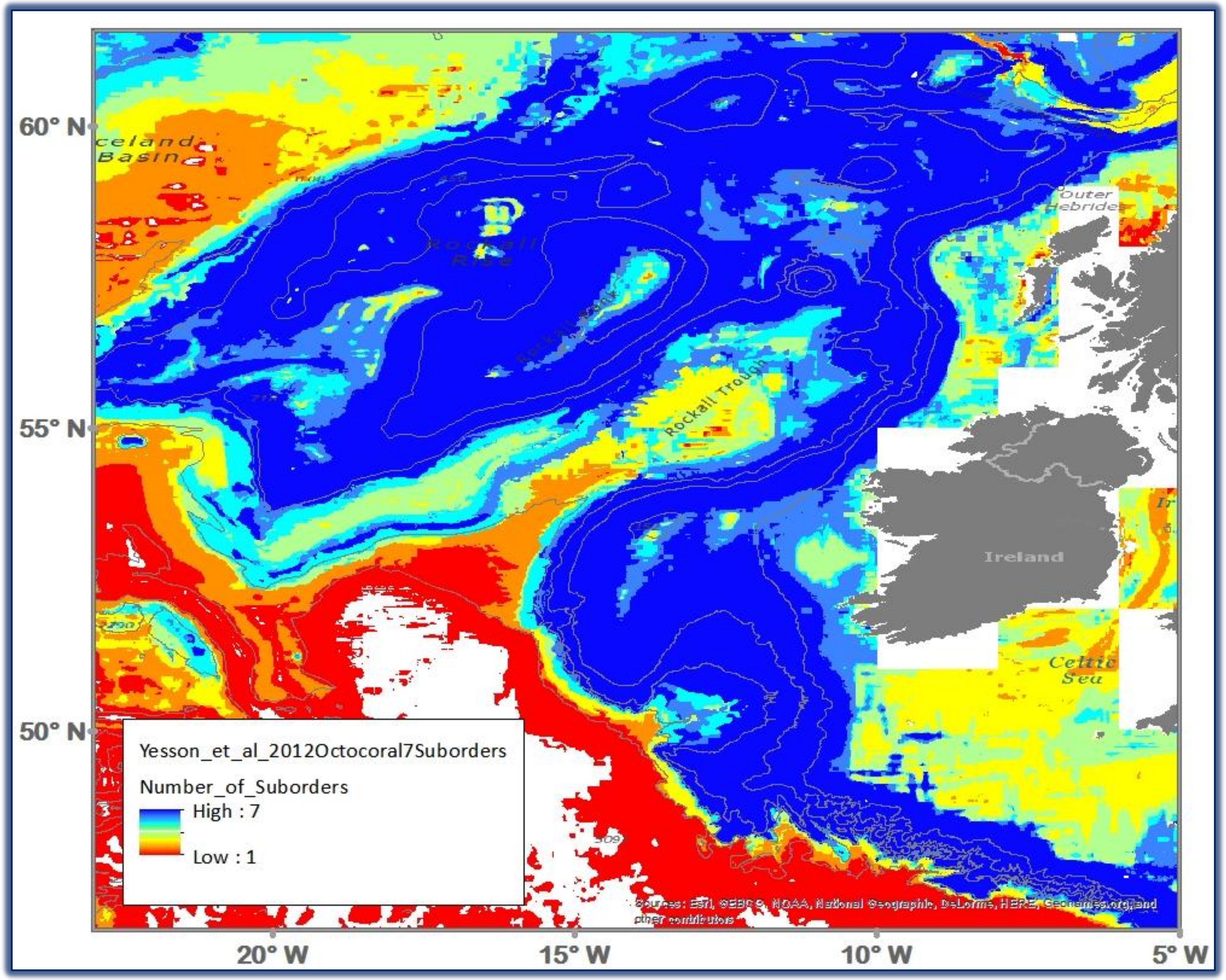


Figure 19 Habitat suitability map for seven Octocorallia sub-order taxa in the Irish offshore (from Yesson *et al*., 2012). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

2.4 Ecology

2.4.1 Physico–chemical environment

2.4.1.1 Water body characteristics

Waters bathing geogenic and biogenic reefs, and carbonate mound structures along the Irish continental margin belong to two major components of the north-east Atlantic circulation system (see Figure 20) (Dullo *et al*., 2008). The upper-layer water mass, the Eastern North Atlantic Water (ENAW), is part of the North Atlantic Current (NAC) and is formed mainly during the winter months in the Bay of Biscay. Seasonally, a surface layer of up to 50 m to 100 m thickness develops and is modified by atmospheric interaction. It is characterised as an increase in surface temperatures from approximately 4°C to 6°C (Holliday & Cunningham, 2013). The other important component of the north-east Atlantic circulation is the Mediterranean Outflow Water (MOW) (Holliday & Cunningham, 2013; White, 2007; White *et al*., 2005) which forms the major intermediate water mass. The MOW is characterised by an increase in salinity and potential temperature in comparison to over- and under-lying water masses.

In the Porcupine Seabight the MOW mass which exhibits a thickness of around 600 m has its core located at around 1,000 m water depth. The MOW mass can be differentiated in the Gulf of Cadiz into a higher density lower core located at around 1,250 m depth and a lower density upper core at around 750 m depth (Dullo *et al*., 2008). The upper core of the MOW flows farther north along the European continental margin underlying ENAW. Upper portions of this MOW mix with ENAW in the eastern North Atlantic and with Subarctic Intermediate Water (SAIW) in the western North Atlantic, while lower portions mix with Labrador Sea Water (LSW) (Holliday & Cunningham, 2013; White, 2007; White *et al*., 2005). Within the Porcupine Seabight, warm, saline water fills the upper layer down to about 600 m depth. This water mass is of ENAW origin, carried northwards adjacent to the north-east Atlantic margin (Pollard *et al*., 1996). A high salinity level marks the MOW, which occupies the whole basin between 800 m and 1,000 m depth.

The upper level of MOW is associated with the permanent thermocline. The thermocline matches the mean water depth where carbonate mounds are found. The MOW is also present west of the Porcupine Bank, but its signal rapidly diminishes north of 53°N because it re-circulates west of the bank (Dullo *et al*., 2008). Surface water masses around Rockall Bank are derived from a north-western branch of ENAW and North Atlantic Waters, as well as, from fresher, modified North Atlantic Water, the SAIW from the north and west (Lankhorst & Zenk, 2006). Detached pockets of MOW reach the western Rockall Bank at water depths between 800 m and 1,100 m (Harvey, 1982). Beneath these pockets lie intermediate water still showing ENAW characteristics. In contrast to the Porcupine Seabight where ENAW and MOW dominate the intermediate hydrography, the southwestern Rockall Bank shows the influence of SAIW at the surface to a water depth of around 300 m and of LSW at greater depths (Bower *et al*., 2002; Harvey, 1982).

The presence of these conditions at coral mounds has been linked to water-mass interfaces by Dullo *et al*. (2008), who demonstrated that while cold-water corals in the North Atlantic tolerate a wide range of environmental conditions, living cold-water coral reefs tend to occur within a specific density envelope of sigma-theta (δΔ) = 27.35 to 27.65 kg/m^3 (see Figure 21), thus highlighting the importance of physical boundary conditions for cold-water coral growth and distribution.

The major environmental conditions influencing the distribution of coral reef species (i.e. water temperature, salinity) are presented above. However, the occurrence of reef, and in particular the formation of carbonate mound structures, appear to be controlled by the occurrence of environmental conditions optimal for coral growth. These include local current strength, sedimentation rate, and water chemistry (*e.g*. Dorschel *et al*., 2005; Dullo *et al*., 2008; Thierens *et al*., 2010).

One generally accepted theory proposed for coral reef distribution is the ‘current acceleration hypothesis’ that suggests that coral reefs occur in areas of accelerated currents and sloping topography, where currents act to channel suspended food to the habitat-forming sessile corals (*e.g*. see Davies *et al*., 2008; Mortensen *et al*., 2001 Thiem *et al*., 2006) and reduce localised sedimentation rates (White *et al*., 2005). The current acceleration hypothesis is supported by habitat suitability modelling studies (see Section 2.3.2 above), that indicate the major environmental parameters influencing coral distribution are predominately those typifying environmental conditions, at sloping topographies, and topographic highs (Davies *et al*., 2008; Reed *et al*., 2013).

As mentioned above, extensive coral reef formations are found along areas of sloping bathymetry where strong currents act to concentrate particulate food. Trophic studies of the reef community on the Galicia Bank, north-west Spain (Duineveld *et al*., 2004) and Rockall Bank, north-west of Ireland (Duineveld *et al*., 2007), indicate that the coral are obligate filter feeders, whose food source is suspended organic particles. As obligate filter feeders, cold-water corals rely upon the supply of organic material such as phytodetritus, faecal pellets and zooplankton for growth (Duineveld *et al*., 2004, 2007; Frederiksen *et al*., 1992; Roberts *et al*., 2009; Thiem *et al*., 2006). In addition to channelling food to the coral, these water currents are also thought to play an important role in the removal of waste products, the exchange of gametes and dispersal of larvae (Roberts *et al*., 2009).

The habitat-forming species at geogenic reefs are typically filter feeders. Black corals require fast and consistent currents and tend to be found in areas of accelerated currents such as seamounts (Wagner *et al*., 2011). Currents are similarly important for octocorals (Genin *et al*., 1986; Tittensor *et al*., 2009; Yesson *et al*., 2012). Thus, it is not surprising to find both black coral and octocoral prevalent in submarine canyons where the steep and complex topography influences current patterns.

Soetaert *et al*. (2016) demonstrated that the positive feedback between cold-water coral growth on carbonate mounds, and enhanced food supply essential for their sustenance in the deep sea, represents an example of ecosystem engineering. Model simulations were used to show that the interaction between tidal currents and carbonate mounds induces down-welling of surface water that brings rich organic matter into contact with the 600 m deep cold-water coral reefs.

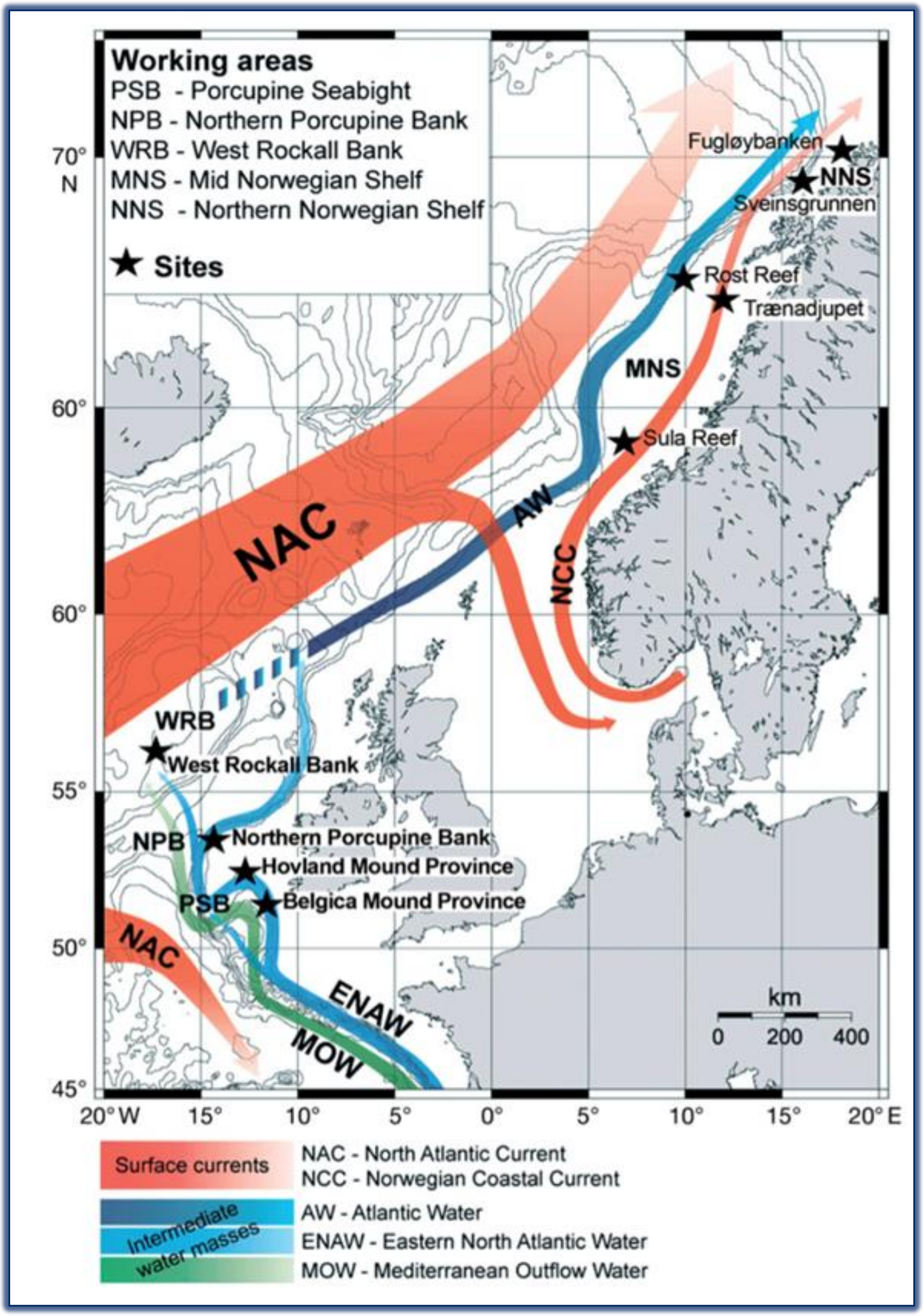


Figure 20 Investigated locations of cold-water reefs along the Celtic and Norwegian Margin and prevailing current regimes (from Dullo *et al*., 2008). Red arrows indicate surface currents of the North Atlantic Current (NAC) and the Norwegian Coastal Current (NCC), blue and green arrows indicate intermediate water mass circulation of Mediterranean Outflow Water (MOW), the overlying Eastern North Atlantic Water (ENAW) and Atlantic Water (AW).

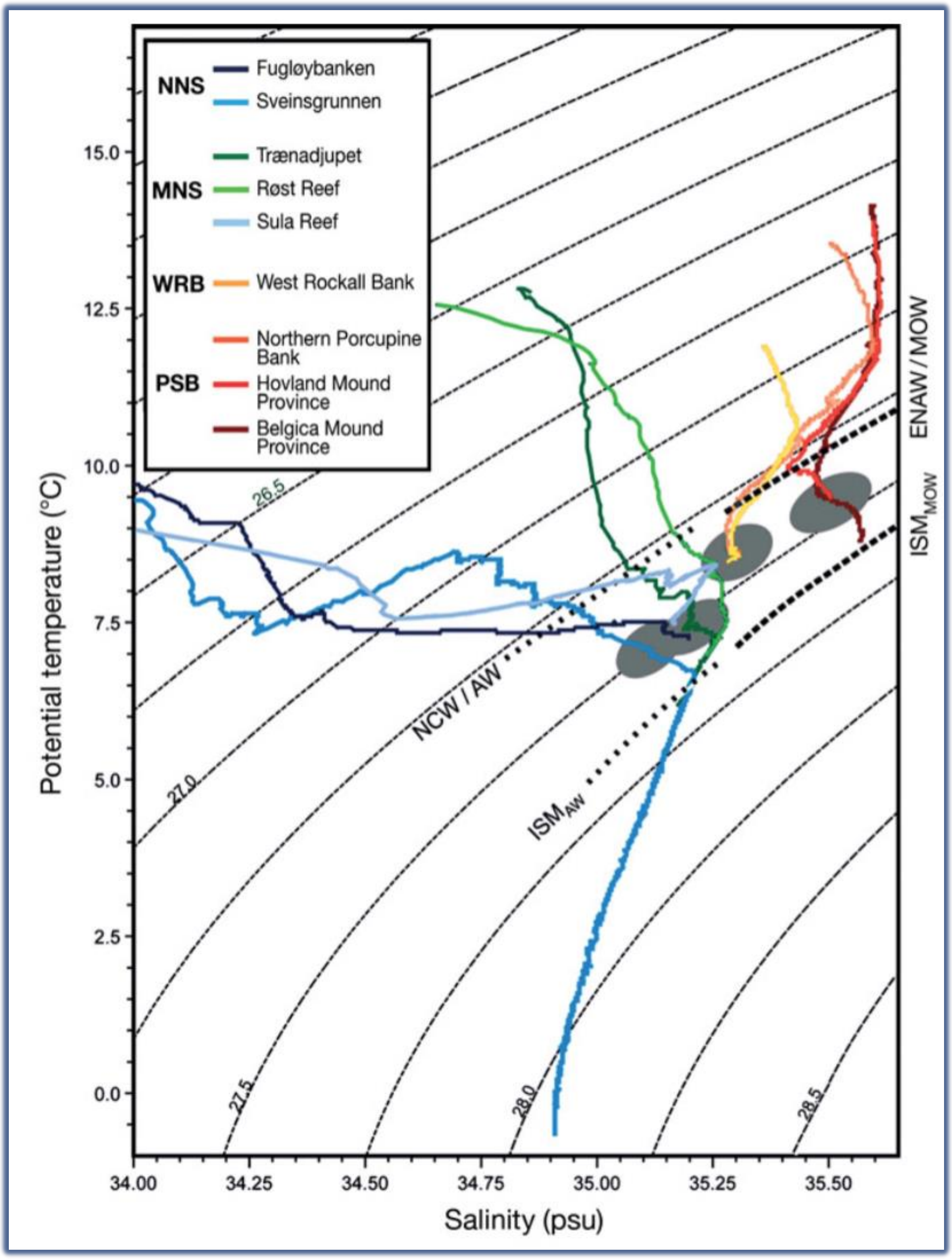


Figure 21 Temperature – Salinity plot of known coral sites in Dullo *et al*. (2008). Thin dashed lines indicate levels of iso-density (δΔ) in kg/ m^3. Grey patches show habitats of living cold-water coral reefs. The lower limit is confined by the Intermediate Salinity Maximum (Hernández-Kantún *et al*., 2012) corresponding to Mediterranean Outflow Water (ISM/ MOW) on the Celtic margin and to Atlantic Water (ISM/ AW) on the Norwegian margin. The upper limit is characterized by the water mass boundaries of Eastern North Atlantic Water (ENAW)/MOW (Celtic sites) and Norwegian Coastal Water (NCW)/AW (Norwegian sites). MNS: Mid-Norwegian Shelf; NNS: Northern Norwegian Shelf; PSB: Porcupine Seabight; WRB: Western Rockall Bank

2.4.1.2 Hard substrate

The availability of hard substratum has been shown to be an important factor influencing initial settlement of larvae. For instance, Freiwald *et al*. (1999) related the occurrence of large reef formation to the availability of large areas of hard substratum exposed as a result of glacier scour. Wilson (1979) and, Wilson & Vina Herbon (1998) reported extensive settlement of reef polyps on cobble and small boulders that can grow and coalesce to form extensive patch-reefs. These extensive reefs can measure several metres across and can be long lived (> 1,000 years), growing at a rate of about half a centimetre each year (Mortensen *et al*., 2001). It should be noted, however, that in areas where conditions for growth are optimal, reef formation can be considerably faster (Rogers *et al*., 2007). For instance, the Scleractinian coral *Lophelia pertusa* colonising oil rig structures in Norwegian waters exhibit growth rates of up to 33 mm/year (Roberts *et al*., 2009). Where reef persists over time, successive generations of coral reef growth can form extensive carbonate mound structures (see Section 2.3.1.5 above) which can rise up to 350 m from the seabed (De Mol *et al*., 2002; Hovland *et al*., 1998; OSPAR, 2010; Roberts *et al*., 2009).

Geogenic reef is defined as reef formed on hard substrate, and this substrate is a requirement for the settlement and attachment of the habitat-forming species, which include octocorals, black corals and sponges (Johnson *et al*., 2013). In offshore waters, this substrate tends to be found on the continental slope, particularly in submarine canyons, and on the flanks of seamounts. The Irish margin has a very large number of submarine canyons. Submarine canyons are the prominent morphological feature of the Irish seabed consisting of tens to hundreds of kilometres long, narrow valleys, carved tens to hundreds of meters deep into the margin. These often extend from the shelf break at 200 m water depth all the way down to the lower continental rise at approximately 2,500 m water depth (Dorschel *et al*., 2010).

Harris *et al*. (2014) created a digital seafloor geomorphic features map of the global ocean that provides a quantitative assessment of different geomorphic features along the deep-sea margins of the world's oceans. This map identifies a total of 56 canyons along the Irish margin (see Figure 22). Given that the few canyon areas that have been investigated by remotely operated vehicles (ROVs) have revealed extensive geogenic reef habitat, it is likely the majority of canyons along the Irish margin provide suitable physical habitat for the development of cold-water coral species.

Black corals tend to be scarce in areas with high sediment cover (Wagner *et al*., 2012), probably because, unlike other anthozoans including octocorals, they lack the ability to retract their tentacles and thus have little protection against the smothering and abrasive effects of a high sediment load. Submarine canyons tend to be swept of sediment by their fast currents, proving ideal habitat for black corals.

2.4.1.3 Aragonite/calcite

The deeper waters of the ocean are naturally more acidic than the upper layers, since CO_2 that dissolves at the surface descends with dense cold water as part of the thermohaline circulation. The acidic lower layers of the ocean are separated from the upper layers by a boundary called the 'aragonite saturation horizon' (Dullo *et al*., 2008). Above this boundary there are enough carbonates present in the water to support coral communities.

The skeleton of black corals is composed primarily of protein and chitin (Goldberg, 1991), but octocorals have varying requirements for aragonite and calcite depending on the form of their skeleton. Even the 'softest' Alcyonacea (*e.g*., *Anthomastus* spp.) have microscopic calcium carbonate sclerites for support, while gorgonians and bamboo corals have larger skeletal structures with an obvious calcium requirement. Yesson *et al*. (2012) found that variation in calcite saturation was the major factor influencing octocoral distribution on a global scale.

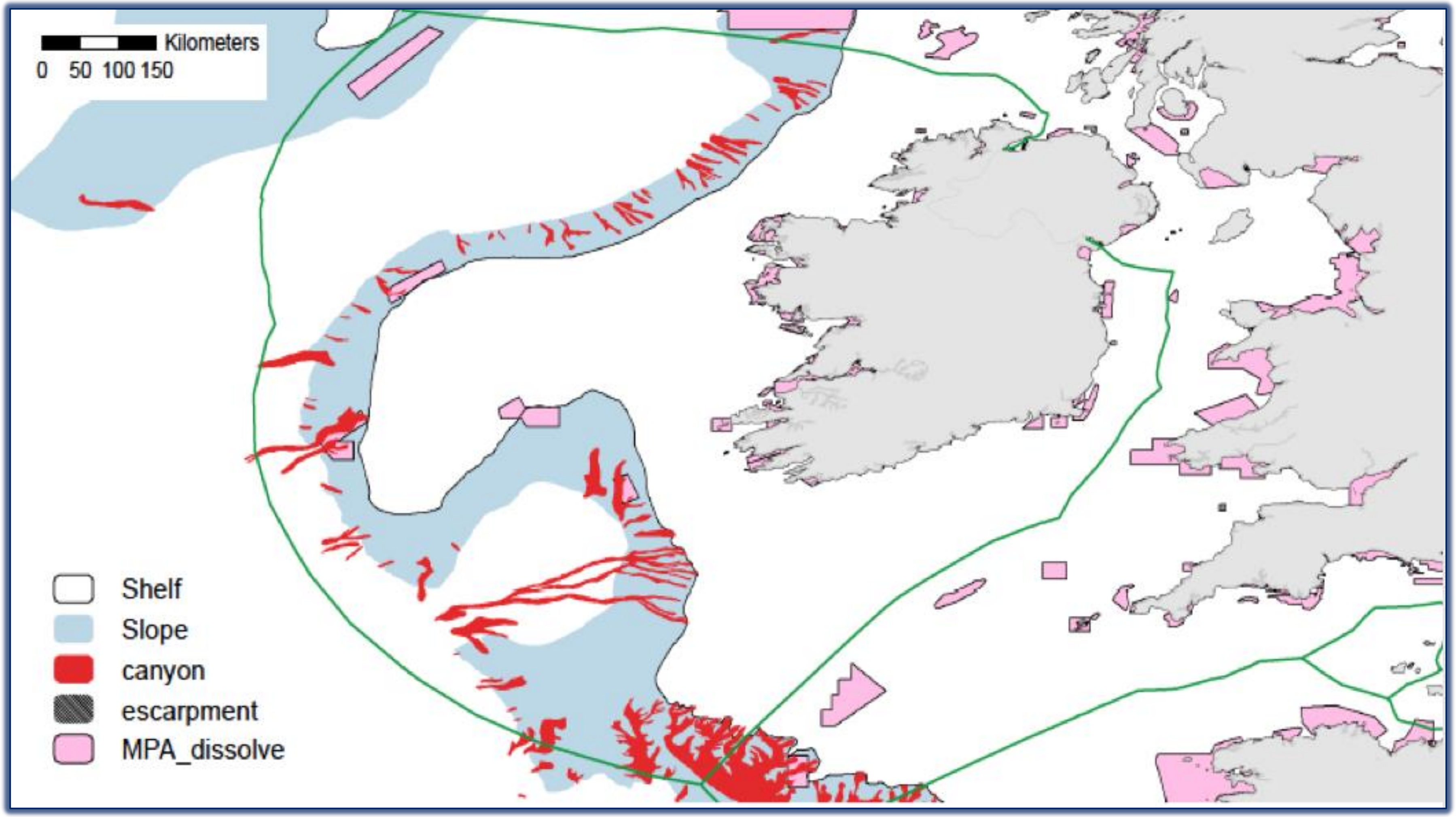


Figure 22 Quantification of Irish seafloor geomorphic features (from Harris *et al*., 2014). The location and extent of current marine protected areas is also shown.

2.4.2 Reproductive biology, growth rates, and longevity

2.4.2.1 Reproductive biology

Most cold-water Scleractinians (including *Lophelia pertusa*) are gonochoristic, *i.e*. have separate sexes (Waller & Tyler, 2005). The dominant strategy for reproduction appears to be broadcast spawning whereby gametes are released to the water column, where fertilisation and larval development occurs (Larsson *et al*., 2014)

Seasonal phytoplankton blooms have been reported in July for the Porcupine Seabight (Lampitt *et al*., 2001). The surface primary production sinks rapidly to the seafloor (Billett *et al*., 1983; Lampitt *et al*., 2001; Thiel *et al*., 1989) where it is thought to initiate gametogenesis in corals (e.g., Waller & Tyler, 2005) due to a substantial increase in the availability of particulate organic material (POM) (Dullo *et al*., 2008). This coincides with the energetically expensive onset of gamete production in *Lophelia pertusa*. This gamete growth continues in *Lophelia pertusa* until the gametogenic cycle is completed. According to Waller & Tyler (2005), broadcast spawning takes place in January/February.

While *Lophelia pertusa* appears to exhibit seasonal reproduction, Waller & Tyler (2005) suggest that the evidence for seasonal reproduction in *Madrepora oculata* is equivocal. *Lophelia pertusa* produces a single cohort (of around 3,000 oocytes), whereas *Madrepora oculata* produces two cohorts. The maximum observed oocyte size in *Lophelia pertusa* was 140 µm and in *Madrepora oculata*, 405 µm.

Embryogenesis and larval development in *Lophelia pertusa* has been described by Larsson *et al.* (2014) based on laboratory observations. Embryos developed in a more or less organised radial cleavage pattern from 160 µm large neutral or negatively buoyant eggs, to ciliated planulae larvae measuring between 120 µm and 270 µm long. Embryogenesis was slow with cleavage occurring at intervals of six to eight hours up to the 64-cell stage. Larvae were active swimmers (0.5 mm/s), initially residing in the upper part of the water column, with bottom probing behaviour starting three to five weeks after fertilisation. Nematocysts had developed by day 30, coinciding with peak bottom-probing behaviour, and possibly an indication that larvae were fully competent to settle at this time. Planulae survived for eight weeks under laboratory conditions, and preliminary results indicate that these planulae are planktotrophic.

There are three types of Scleractinian larvae: buoyant larvae that rise to the sea surface, neutral larvae that drift with the current staying submerged, and negatively buoyant, crawling larvae. The late onset of competency and larval longevity observed by Larsson *et al*. (2014), suggests a high dispersal potential. Dullo *et al*. (2008) speculate that gametes could have densities that limit their concentration and lateral transport to the density envelope of 27.35 to 27.65 kg/m^3 (see Figure 21), since above and below these levels all coral mounds are dead. No studies have reported the collection of *Lophelia* or *Madrepora* larvae in situ although settlement experiments in the field have picked up early settlement stages (Lavaleye, pers. comm.).

Potentially habitat-forming Alcyonacea genera listed by Freiwald *et al*. (2004) that are found in Irish waters are *Paragorgia*, *Paramuricea*, *Primnoa*, *Narella*, *Acanella*, *Isidella* and *Keratoisis*. *Candidella*, *Jasonisis* (newly described in 2012 by Alderslade & McFadden), and *Lepidisis*, based on either their size or structure, might also contribute substantially to habitat formation.

Alcyonaceans exhibit one of two types of sexual reproduction strategy: broadcast spawning and brooding. In the case of brooding (and in contrast to broadcast spawning) fertilisation occurs on/in the female colony, with the eggs subsequently brooded either in autozooids, siphonozooids or specialised brood chambers or adhered to the adult colony (Watling *et al*., 2011). The two strategies appear to be evolutionarily plastic, with both occurring in some genera. Broadcast spawners include *Primnoa resedaeformis, Keratoisis ornata, Acanella arbuscula,* and several North Atlantic species of *Paramuricea.* Environmental conditions in the deep sea are predicted to favour a brooding strategy, although broadcast spawning behaviour demonstrated by many species of deep-sea sea pens (Order Pennatulacea) contradicts this (Watling *et al*., 2011). Colonies may not allocate resources to reproduction until they reach a certain size, and larger colonies appear to be more fecund (Beazley, 2011; Mercier & Hamel, 2011). However, *Acanella arbuscula* has been shown to be sexually mature at less than 3 cm height and increasing fecundity appears to be related to a change in morphology rather than size (Beazley, 2011).

Most octocorals are gonochoristic within colonies, and there are no known exceptions to this in the genera considered here, although data are sparse (Allcock, pers. comm.). Eggs and sperm develop in specialised areas of the ventral and lateral mesenteries and synchronous gamete development has been noted in *Keratoisis ornata*, suggesting potential seasonal reproduction (Watling *et al*., 2011).

Potentially habitat-forming Antipatharia genera listed by Freiwald *et al*. (2004) that are found in Irish waters include *Antipathes, Trissopathes, Bathypathes, Parantipathes, Stauropathes,* and *Leiopathes*. It is likely that *Telopathes*, which was first described in 2013, also contributes to habitat formation (Allcock, pers. comm.).

Reproduction in Antipatharia was reviewed by Wagner *et al.* (2011). Most research has focused on shallow-water species, although a few studies have looked at specimens collected from more than 1,000 m depth. Studies have found the polyps of black corals to be gonochoristic for the most part (the exception to date being a species of *Stichopathes*). Both oocytes and spermatophores tend to be small (less than 500 µm). Internal fertilisation has not been identified in any of the studied specimens and fertilisation and larval development are thus inferred to take place in the water column (Wagner, 2012). No studies of seasonality have been conducted for deep-water species and no deep-water larvae have been observed (Allcock pers. comm.).

Asexual reproduction can occur in black corals, through budding of new polyps, fragmentation, production of asexual larvae, and ‘polyp bailout’. Asexual larvae have been elicited under stress in laboratory conditions. Similar conditions have led to portions of polyps detaching from colonies to form ciliated planulae larvae – a bailout strategy known in other hexacorals. Molecular work that has identified clonal lineages suggests that asexual strategies may occur in the wild, but they have never been observed, and research again focuses on shallow-water species. For review, see Wagner (2012).

2.4.2.2 Growth rates and longevity

Growth rates and longevity may be measured together, particularly when the methods involved utilise growth rings in the axial skeleton. Scleractinian species are very long-lived and their skeletal remains are among the longest-lasting cold-water coral structures, providing important habitats for diverse communities (Roberts *et al*., 2009). Estimates of growth rates in *Lophelia pertusa* vary widely. Direct observation of coral structures in the north-east Atlantic indicate growth rates range between 5 mm to 34 mm/year (Duncan, 1878; Wilson, 1979; Bell & Smith, 1999; Roberts, 2002; Gass & Roberts, 2006) while laboratory aquaria observations suggest growth rates vary between 15 mm and 17 mm/year (Orejas *et al*., 2008). In the case of *Madrepora oculata* maintained in aquaria growth rates ranged between 3.0 mm and 18 mm/year.

Octocorals tend to be long lived, with colony ages generally in the tens to hundreds year range, however, there is considerable variation in estimates. Focusing only on deep-sea samples, *Paramuricea* colonies have been found to survive 599 years (Prouty *et al*., 2016), *Chrysogorgia* to 464 years (Prouty *et al*., 2016), *Primnoa* to more than 300 years (Risk *et al*., 2002) and *Paragorgia* to 80 years (Sherwood & Edinger, 2009). Among bamboo corals, *Acanella* has been found to live to 100 years (Sherwood & Edinger, 2009), *Isidella* to 53 years (Andrews *et al*., 2009) and *Lepidisis* to 45 years (Sherwood & Edinger, 2009). Younger dates have also been obtained and dates probably vary by depth, water temperature, species, and even methodology used. No information on ages of specimens from Irish waters is available and it is likely that fishing may have removed a proportion of older colonies in some locations

(Sherwood & Edinger, 2009). Growth rates tend to be low. Studies that use stable isotopes to estimate longevity tend to provide estimates of radial growth that are less intuitive to interpret. Radial growth of bamboo corals tends to be less than 0.1 mm/year while axial growth is less than 1 cm/year (reviewed in Watling *et al*., 2011). Longer-lived species such as *Paramuricea* have correspondingly lower growth rates, see Prouty *et al*. (2016) for details.

Antipatharian black corals are generally inferred to have greater longevity and to be slow growing. *Leiopathes* from Hawaii and the south-eastern US from depths between 300 m and 500 m were estimated, on the basis of radiocarbon (^{14}C) dating and growth ring counts, to be between 350 and 4,250 years old (Roark *et al.*, 2006, 2009; Prouty *et al.*, 2011). These estimates however represent the extreme upper limit of black coral ages. *Leiopathes glaberrima* from south-eastern US waters at similar depth has been estimated at 198 to 483 years on the basis of ^{210}Pb dating and growth ring counts, while *Stauropathes arctica* from deeper waters (approx. 800 m) off Newfoundland has been estimated at 33 to 66 years based on ^{14}C data (Sherwood & Edinger, 2009). Naturally extreme ages are mirrored by extremely slow growth. Reported radial growth in *Leiopathes* species varies between 0.005 mm and 0.02 mm/year. In other species radial growth of 0.04 mm to 0.66 mm/year translated to vertical growth of 1.22 cm to 1.36 cm/year, growth of 0.1 mm/year translated to vertical growth of 1.3 cm to 1.8 cm/year, and radial growth of 0.92 mm/year translated to vertical growth of 5.7 cm/year (see Wagner 2011, 2012). Greatest growth rates have been measured in shallow water species of *Stichopathes* and *Cirrhipathes via* direct tagging of colonies with rates exceeding 70 cm/year and 150 cm/year respectively (Warner, 2005; Bo *et al*., 2009).

2.4.3 Population genetics and connectivity

Studies of connectivity and gene flow between *Lophelia pertusa* populations have depended on indirect methods that compare neutral genes, *i.e*. genes that do not affect adaptive fitness of an individual among populations (Dahl *et al*., 2012; Le Goff-Vitry *et al*., 2004; Morrison *et al.*, 2011). Studies of *Lophelia pertusa* populations in the North Atlantic Ocean using genetic markers suggest that some gene flow is taking place across large geographic distances. This indicates that *Lophelia pertusa* produces a relatively long-lived, effectively dispersing larval stage, a hypothesis that is further supported by the fact that it has colonised North Sea oil platforms far from known reef sites (Bell & Smith, 1999; Gass & Roberts, 2006; Roberts, 2002).

Investigations of population genetics of both *Lophelia pertusa* and *Madrepora oculata* from the Mediterranean to Iceland indicate that while levels of genetic diversity appear similar for both species, differences in distribution were observed (CoralFISH, 2013). *Lophelia pertusa* has a homogeneous distribution while *Madrepora oculata* has a more heterogeneous pattern (see Figure 23). This has major implications for the preservation of reef systems comprising the two species, as it implies a network of protected areas should accommodate representativeness and connectivity for the two contrasting species. To encompass global genetic diversity, a network of protected areas should address the regional scale variation as all regions (*i.e.* Mediterranean, Bay of Biscay, Iceland, and Ireland) seem to support slightly distinct genetic pools. The scale of dispersal of *Lophelia pertusa* in the Mediterranean-Northern Atlantic region indicates that reef connectivity should be addressed at the regional scale, while in the case of *Madrepora oculata,* which appears to be slightly differentiated within the Bay of Biscay, connectivity should be addressed at a finer geographical scale.

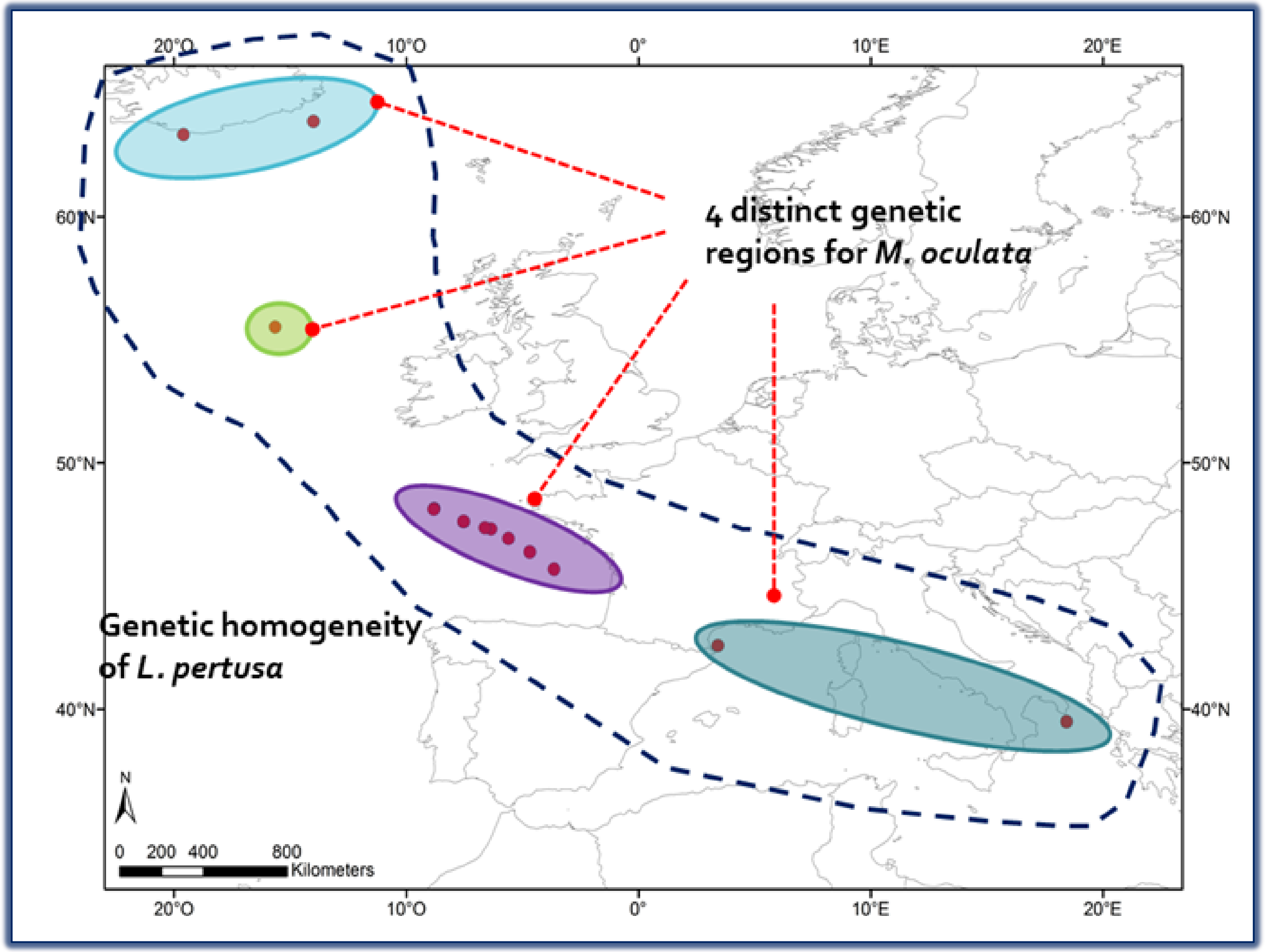


Figure 23 Map illustrating the genetic connectivity, highlighting genetically distinct areas (colour patches) for *Madrepora oculata* and the rather homogeneous distribution of apparently highly connected populations of *Lophelia pertusa* (dots) (from Arnaud *et al*., 2013).

2.4.4 Community biodiversity – Description of faunal assemblages at geogenic and biogenic reef

Biodiversity at biogenic and geogenic reefs is dependent on the presence of habitat-forming coral species, the occurrence and distribution of which is driven by the physical and chemical requirements of the coral species (as discussed in Section 2.4.1 above). In the case of biogenic reef communities, hermatypic Scleractinian species play the primary role in influencing biodiversity, and to a lesser extent ahermatypic octocorals and antipatharian species (Freiwald *et al*., 2004; NPWS, 2013a, b; OSPAR, 2010a; Roberts *et al*., 2006, 2008; Sumina & Kennedy, 1998). In contrast, biodiversity at geogenic reef associated communities, such as those found in canyon complexes, is primarily influenced by the occurrence of octocorals and antipatharians (Buhl-Mortensen & Mortensen, 2004; Edinger 2007; Söffker *et al*., 2011; Stone, 2006). A list of species recorded at reef habitats in the Irish offshore is included in Appendix A (Table 3).

2.4.4.1 Biogenic reef assemblages

As well as supporting a diverse array of sessile suspension feeding bryozoans, anemones and sponges, coral reef and carbonate mound habitats support mobile grazing, scavenging and predatory fauna including starfish, sea urchins, polychaetes, crustaceans and fish (Freiwald *et al*., 2004; NPWS, 2013a, b; OSPAR, 2010; Roberts et al., 2006, 2008; Sumina & Kennedy, 1998). It has been estimated that diversity at these habitats can be as much as three times that of surrounding seafloor sedimentary habitats (Henry & Roberts, 2007; Jensen & Frederiksen, 1992; Jonsson *et al*., 2004; Mortensen *et al*., 1995; Ramirez-Llodra *et al*., 2010), with Husebø *et al*. (2002) reporting ten times more squat lobsters in coral habitat than the surrounding seabed.

Over 1,300 species have been recorded at *Lophelia pertusa* coral reefs in the OSPAR area (OSPAR *et al*., 2010). Commonly associated species include invertebrates such as echiurans (*e.g*. *Bonellia* spp.), molluscs (*e.g*. *Acesta excavata*), shrimp (*Pandalus* spp.), squat lobsters (*Munida* spp.) and echinoderms such as pencil sea urchins *Cidaris* spp. and basket stars *Gorgonocephalus spp*. (Freiwald *et al*., 2004; Hovland, 2008; OSPAR, 2010; Roberts *et al*., 2006, 2008).

Sampling at carbonate mounds in the Porcupine Basin has revealed diverse communities of sponges, bryozoans, hydroids, soft corals, ascidians, calcareous tube worms, crinoids and bivalves colonising the surface of dead coral branches standing proud of the seabed, while underlying coral rubble supported burrowing eunicid worms, sipunculids, and suspension feeding ophiuroid echinoderms and bivalves (OSPAR, 2010).

Carbonate mounds can comprise a variety of habitat types including coral reef, coral rubble, stabilised and mobile sediments, and cobble grounds, each supporting distinct macrofaunal communities (Wheeler *et al*., 2005; Wienberg *et al*., 2008; OSPAR, 2010). On the Franken Mounds on the Rockall Bank, Wienberg *et al.* (2008) described distinct faunal assemblages associated with discrete live coral colonies, dense coral framework coverage, coral debris fields and soft sediment. Discrete coral colonies were composed of species from the coral taxa Octocorallia, Antipatharia and Scleractinia, with a variety of associated sponges, hydroids and anemones (Actinians). Dense coral reef habitats predominately consist of live and dead Scleractinians, octocorals, Actiniarians and sponges. Coral debris fields have been found to support two distinct assemblages of sponges and cnidarians growing on *Lophelia* spp. debris while soft sediment areas support infaunal assemblages. Similarly, a study investigating the macrofaunal assemblages of biogenic carbonate habitats of the Porcupine Bank and Rockall Bank (Wilson & Vina Herbon, 1998) reported diverse assemblages of echiuran worms, cerianthid anemones and caridean shrimps inhabiting carbonate mound sediment habitats.

At the Belgica Mound Province, Henry & Roberts (2007) compared macrobenthos between on- and off-mound habitats. They recorded 349 species, including 10 undescribed species and showed that on-mound habitat was three times more species diverse, and was richer with higher evenness and significantly greater Shannon's diversity than off-mound. Species composition differed significantly between habitats and the four best discriminating species were *Pliobothrus symmetricus* (more frequent off-mound), *Crisia nov.* spp, *Aphrocallistes bocagei* and *Lophelia pertusa* (all more frequent on-mound). Filter/suspension feeders were significantly more abundant on-mound, while deposit feeders were significantly more abundant off-mound.

Based on video observations conducted using an ROV at the Macnas Mounds, Wilson *et al*. (2007) demonstrated that the mound and inter-mound areas contained distinct habitats hosting contrasting fauna. Observations showed that the mounds are colonised by squat lobsters (*Munida* spp.) living on coral rubble, whilst the inter-mound areas consist of soft sediments, often colonised by anemones. Furthermore, Husebø *et al*. (2002) reported squat lobsters abundance to be ten times higher in coral habitat than the surrounding seabed. It is unclear whether the observed coral rubble found on the mounds resulted from the natural disintegration of long dead coral stands or resulted from modern day destruction linked to the recent advent of industrial trawling in the area as anecdotal information suggests. This is a moot point, as it is the coral rubble that provides suitable habitat for the *Munida* to thrive.

A number of deep-sea fish species use biogenic carbonate mound and reef habitat for refuge, feeding, spawning and nursery areas, (Biber *et al*., 2014; Buhl-Mortensen *et al*., 2010), with several studies reporting a relationship between fish and cold-water coral habitats in the North Atlantic (Costello *et al*., 2005; Duran Munoz *et al*., 2011; Husebø *et al*., 2002; Söffker *et al*., 2011). In particular, rockfish species (*e.g. Sebastes viviparous*), (ICES, 2009; OSPAR, 2009) can be found sheltering and feeding in and around coral reef structure and rubble, while Orange Roughy (*Hoplestethus atlanticus*) aggregate in the vicinity of these features to spawn (Shephard & Rogan, 2006). A number of fish species, including Tusk *Brosme brosme* (Ascanius, 1772), are associated with coral by diet (Husebø *et al*., 2002; Mortensen *et al*., 1995). In the case of Tusk, it was further suggested that individual fish occurring on- and off-reef habitat adjust their diet based on what is abundant (Husebø *et al*., 2002), inferring that while coral habitat is not essential for Tusk, it provides a greatly enriched food source, thus supporting a higher density of the species.

Linley *et al*. (2015) used baited, autonomous, photographic landers to compare both the time of first arrival (*T arr*), and the maximum observed number of fish (*Max N*), between coral and reference stations, as indicators of local fish density at a number of European sites including the Belgica Moulds. Fish reached significantly higher *Max N* at the coral stations than at the reference stations. Fish also tended to have significantly lower *T arr* in the coral areas. All data indicated that fish abundance is higher within the coral areas with twice as many fish species being observed and estimated in the coral deployments in the Belgica Mounds than during reference deployments. The rockling-like fishes *Gadiculus argentatus* and *Benthocometes robustus*, were only seen in the coral areas of the Belgica Mounds as they emerged from the coral lattice itself. Söffker *et al*. (2011) also reported two fish living among the coral in the Belgica Mounds. One was described as strongly resembling *Gaidropsarus* spp. (Rockling) while the second was identified as *Guttigadus latifrons*, a species closely resembling *Benthocometes robustus*. These observations suggest at least two species are strongly coral associated and make direct use of the coral structure in the Belgica Mounds. This potentially represents an example of essential use of the reef as a fish habitat. Linley *et al*. (2015) recommend that further work is required to validate species identification, and in particular to reveal the highly cryptic element of the fish community that appears to live within the cold-water coral reefs. Ross & Quattrini (2007), during a study off the south-eastern United States, reported that several fish species spent long periods within the coral structure and were only detectable when flushed out through the use of rotenone (a broad-spectrum piscicide). It was proposed by Carrassón & Matallanas (2002) that small Rockling-like species may use the coral to avoid predation.

2.4.4.2 Geogenic reef assemblages

Geogenic reef communities commonly form multispecies assemblages of octocorals and antipatharians (or ‘coral gardens’) (Freiwald *et al*., 2004) which create structural habitat for other fauna (Buhl-Mortensen & Mortensen, 2004; Edinger, 2007; Söffker *et al*., 2011; Stone, 2006; Wagner, 2012).

Davies *et al.* (2014) defined deep-water biotopes from the Dangeard and Explorer canyons, located in south western UK waters, which feed into the Whittard Canyon. Five out of twelve biotopes were associated with bedrock. The characteristic fauna of two of these biotopes comprised cerianthid anemones, which are associated with the overlying sediment and not the bedrock itself, thereby disqualifying the habitat as geogenic reef, following the interpretation of Johnston *et al*. (2002). Two further habitats, named *Lop.Hal* and *Lop.Cri* respectively, included elements of biogenic reef. The *Lop.Hal* biotope comprised live and dead *Desmophyllum pertusum,* providing habitat for burrowing and tube anemones and substrate for *Madrepora oculata,* Acanella, ascidians and crinoids. The *Lop.Cri* biotope comprised live and dead *Desmophyllum pertusum*, providing habitat for *Psolus squamatus*, *Stichopathes* spp. and crinoids. A third reef biotope (*Bat.Hyd*) comprised *Bathylasma* spp. (*Balanomorpha cirripedes*) and hydroids on bedrock.

Davies *et al.* (2015) defined thirteen deep-water biotopes describing benthic assemblages on the Anton Dohrn Seamount. Three of these biotopes, which were described by Davies *et al*. (2015) as ‘coral gardens’, could be considered geogenic reef habitat: (*Lep.Par*) coral garden with bamboo corals and antipatharians on bedrock; (*Ker.Sol*) coral garden with bamboo corals and *Solenosmilia variabilis* on bedrock; (*Gor.Zoa*) mixed corals and zoanthid coral garden. Similar habitats to all three of these biotopes have been recorded in Whittard Canyon (Allcock, unpublished).

Two separate vertical wall habitats have been described from Whittard Canyon, one at 600 m to 800 m at the channel heads, dominated by the limid bivalve *Acesta excavata* and the deep-water oyster *Neopycnodonte zibrowii* (Johnson *et al*., 2013); the other at 1,300 m to 1,600 m dominated by *Primnoa resaediformis* and *Desmophyllum pertusum* (Huvenne *et al*., 2011). Apart from these two well-described habitats, geogenic reefs occur wherever there is exposed bedrock.

Amaro *et al*. (2016) report that Robert *et al*. (2015) found 31 putative coral species out of 210 morphospecies identified during 17 video transects. Neither study provides a list of the coral species, which reflects the difficulties of deep-water coral identification and taxonomy, particularly antipatharian and alcyonacean. Morris *et al*. (2013) also reported 31 coral types. The list identifies two types to species level (*Pennatula aculeata*, *Distichoptilum gracile*), compares one to a known species (*Acanella* cf. *arbuscula*), and identifies a further 13 types to genus level (*Bathypathes* spp., *Lophelia* spp., *Madrepora* spp., *Desmophyllum* spp., *Anthomastus* spp., two *Paragorgia* spp., *Radicipes* spp., *Acanthogorgia* spp., *Primnoa* spp., *Kophobelemnon* spp., *Umbellula* spp., *Anthoptilum* spp.), nine to family level (eight *Isididae* spp., one *Stylasteridae* spp.), four to Order (three *Alcyonacea*, one *Pennatulacea*) and two simply as ‘purple coral’ and ‘peach single polyp’. The species list provided in Appendix A (Table 3), is compiled from species named within relevant publications (Amaro *et al*., 2016; Huvenne *et al*., 2011; Johnson *et al*., 2013; Morris *et al*., 2013; Robert *et al*., 2015) but also draws heavily on unpublished and ongoing studies (Allcock, unpublished) being undertaken in collaboration with taxonomic experts worldwide, some of whom have joined RV Celtic Explorer cruises to canyon habitats, particularly the Whittard Canyon. Because of the paucity of published records checked by taxonomic experts (*e.g*., Henry & Roberts, 2013), this list should be considered preliminary. Furthermore, the majority of studies to date have focused on sessile benthic fauna, and the information available for mobile fauna is even more limited, and is mostly drawn from the unpublished data of Allcock (pers. comm.).

2.4.4.3 Comparison of biogenic and geogenic assemblage biodiversity

The preliminary nature of the list of species associated with geogenic reefs, the lack of focus on associated mobile fauna in published studies, and the limited number of studies that have systematically sampled deep-water geogenic reef, mean that statistically valid comparisons with the biodiversity of biogenic reefs cannot be made due to differences in sampling intensity and method. Nonetheless, it is becoming increasingly clear that deep-water geogenic reefs can be highly diverse. Where coral species are abundant and dense; they greatly increase biodiversity by providing cryptic habitats and through their numerous associate species. Examples in Whittard Canyon include chirostylids on black corals, ophiuroids on octocorals such as *Paramuricea,* crinoids associated with octocorals and glass sponges (*e.g.*, *Koehlermetra porrecta* on *Aphrocallistes beatrix*), zoanthids on sponges, bivalves and corals, and polychaetes on black corals (Allcock, unpublished). For review of deep-sea associations see Buhl-Mortensen & Mortensen (2004) and for a review of known associations with black corals globally see Wagner (2012).

3 Potential pressures and threats

3.1 Fishing

Biogenic carbonate habitats can be significantly impacted by fishing gear, including bottom trawls, gillnets, pots and benthic longlines (Freiwald *et al*., 2004; Rogers *et al*., 2008). While traditionally limited to relatively shallow waters, these fishing activities have taken place in water depths down to 1,500 m (OSPAR, 2010; Roberts *et al*., 2001). This movement of fishing activities into deeper waters has led to declines in the extent and status of carbonate habitat throughout the north-east Atlantic (Grehan *et al*., 2005; Hall-Spencer *et al*., 2002; ICES, 2009; Wheeler *et al*., 2005). Figure 24 below illustrates the distribution of deep-water fishing effort along the Atlantic margin offshore Ireland between the years of 2006 and 2011 (Dransfeld *et al*., 2013). Interactions between the fishing and cold-water coral reef habitats is widespread, as evidenced by cold-water coral being reported as by-catch in commercial fisheries (Rogers *et al*., 2008). Furthermore, side-scan sonar and video surveys of coral reef habitat and carbonate mounds structure have revealed trawl door furrows and broken and crushed coral on the seabed (*e.g*. CoralFISH, 2013).

3.1.1 Fishing activity offshore Ireland

A short review of deep-water fishing métiers (i.e., fishing activities), presented in Grehan *et al*. (2005) and references therein, indicates that exploitation of Irish shelf and slope fish stocks in the depth range where corals are typically found, has been dominated by the French deep-water fleet since the 1980s. The principal species exploited include Orange Roughy *Hoplostethus atlanticus*, Black Scabbard *Aphanopus carbo*, Blue Ling *Molva dypterygia* and Grenadier *Coryphaenoides rupestris*, particularly off the north-western coast. Further south, there is a mixed fishery primarily for Hake *Merluccius merluccius*, Monkfish (or Anglerfish) *Lophius* spp. and Megrim *Lepidorhombus whiffiagonis*, exploited by vessels from Spain, France, and Ireland, as well as a number of flag of convenience vessels. These vessels use trawls, gill nets, and tangle nets as well as long-lining. In the early 2000’s, a small number of Irish vessels successfully targeted Orange Roughy spawning aggregations, with catches increasing from three metric tonnes in 2000 to over 2,200 metric tonnes in 2001. This fishery was subsequently banned, ostensibly due to the collateral damage inflicted on coral reefs found on the carbonate mounds where the fishery was focused. Long-line fisheries for the Portuguese Dogfish *Centroscymnus coelolepis*, deep-water Cod *Mora moro*, and Blue Ling have also developed, while there continues to be a small Spanish and Irish pot fishery, principally for the deep-water Red Crab *Chaceon affinis*.

Typically, demersal trawl fisheries for deep-water species deploy trawls fitted with heavy rock-hopper gear, kept open by otter boards typically weighing in excess of 1,000 kg each (Hall-Spencer *et al*., 2002). The trawls are towed at 5 km to 8 km/h with the otter boards set at some 60 m to 70 m apart. Gear is towed for approximately 4 h/haul, sweeping 20 km to 30 km of seabed. There are regularly four to five hauls per day, so an average trip of 10 days can cover up to 100 km^2 of seafloor. A robust type of bottom trawling gear was developed for fishing Orange Roughy. The technique involves the use of bottom sonar to map target topographical highs such as pinnacles, mounts and mounds prior to fishing. The trawls are fitted with high-resolution headline transducers so that the actual position of the net with respect to the bottom can be constantly monitored. These vessels are also fitted with high-resolution sounders and many use chart mapping systems to generate topographic seabed maps in real time. Orange Roughy tend to aggregate near the summit of topographical highs. Fishing an acoustically identified stock involves shooting the trawl to pass close to the summit of the peak, then allowing the net to sink quickly to drive the Orange Roughy onto the seafloor before towing off into deep-water. This is a high risk technique, as under shooting the trawl during the initial pass over the summit will result in snagging of the net on the side of the topographic features. Only certain tracks on each pinnacle or seamount are suitable for successful operation of this technique.

Static gears are typically anchored in place for a period of hours to days and include a variety of gears such as longlines, gillnets, tangle nets and baited pots (Grehan *et al*., 2004; 2005). Long-liners, predominantly targeting Hake, typically deploy between 100 and 120 lines, typically each longline is equipped with 85 hooks, spaced 3 m apart making between 8,000 and 9,600 hooks average per set, covering some 28 km to 35 km. Gill nets, also used for Hake, are typically 50 m long x 12 m high and are shot in strings of 700 nets with a typical shoot fishing an area of some 35 km. Tangle nets, used principally to catch Monkfish, are deployed in strings of up to 500 nets (50 m long x 5 m high) over 24 km with vessels usually working around three to four strings, totalling 75 km to 100 km of gear. These nets may be left in place for one to two weeks at a time. Baited pots are used to catch deep-water Red Crab. Typically, 100-pot strings are set 50 m apart and weighted using large anchors at each end. A vessel can fish between 300 and 600 pots per fishing day, working two sets of gear on alternate days.

3.1.2 Fishing impacts

A number of papers provide evidence of damage to Irish biogenic reefs (Grehan *et al*., 2004, 2005; Hall-Söffker *et al*., 2011; Spencer *et al*., 2002). While it is likely that all the fishing métiers can have some impact if deployed in areas of coral, dynamic bottom trawling is undoubtedly the practice with the most potential to cause collateral damage both directly through mechanical damage (Carey, 2016; Grehan *et al.,* 2005; Hall-Spencer *et al.,* 2002) and indirectly through increased sedimentation (Wilson *et al*., 2015). The potential severity of individual métier impacts on corals are ranked in Table 2.

Table 2 Potential severity of fishing métier impacts on corals (from Grehan *et al*., 2005).

Métier	Ranking
Trawling	High importance
Long-lining	Medium important
Tangle nets	High importance
Gill nets	High importance
Pots	Low importance

Pham *et al*. (2014a) estimate that one deep-sea bottom trawl will have an impact similar to 296 to 1,719 longlines, depending on the morphological complexity of the impacted habitat. However, it is worth noting that while perceived to be less damaging to benthic habitats than trawls, longlines over coral habitats can damage colonies during gear recovery (Fabri *et al*., 2014).

The devastating impact of bottom trawling has been established for Scleractinian corals (*e.g*., Freiwald *et al*., 2004) and studies suggest that octocoral habitats are similarly vulnerable to direct structural impacts. Octocoral habitats, in particular, are perceived to have low recovery due to slow growth and high longevity (Althaus *et al*., 2009), characteristics that apply even more so to black corals. The EU ban on deep-sea fishing below 800 m agreed on June 30th 2016 will give some protection below this depth (see Section 5).

The periphery and interfluvial ridges of submarine canyons are increasingly targeted by fisheries (Martín *et al*., 2014). Fishing in these ecosystems can damage fragile indicator species such as hermatypic Scleractinians and fragile octocorals (Foley *et al*., 2011) and constant disturbance of soft sediment leads to reductions in both species richness and abundance (Pusceddu *et al*., 2014).

In addition to direct damage to biota, trawling on canyon flanks can impact the seafloor via resuspension of sediments, erosion and organic carbon loss (Puig *et al*., 2012, Martín *et al*., 2014, Sañé *et al*., 2013). Furthermore, these impacts can be imparted over larger areas than those actually trawled, due to advection of resuspended sediments to other (often deeper) parts of canyon systems (Palanques *et al*., 2006; Puig *et al.,* 2012; Martín *et al*., 2014). In

Whittard Canyon, correlations between trawling activity on the interfluves and excessive levels of suspended material at depth have been noted (Wilson *et al*., 2015). Canyons are often considered a refuge for species threatened by towed gear on continental slopes, but sensitive filter feeders such as deep-water corals might be severely impacted by this sediment load. In particular, black corals, due to their preference for low sediment cover, susceptibility to abrasion (Wagner, 2012) and inability to withdraw their polyps, are likely to be impacted by increased sediment loads, with knock-on effects to overall geogenic reef diversity because of their structural role. It should be noted that canyons, due to their complex morphology that precludes trawling activity, may be the last refuges for many habitat forming species (Huvenne *et al*., 2011).

Damage to coral by static gear can result when tangle/gill nets or longlines, dragged along the seafloor during recovery, encounter and snag coral as bycatch or cause displacement of coral on the seafloor (Carey, 2016; Fabri, 2014; Grehan *et al*., 2005). Ghost fishing by lost gear is another potentially serious issue, and has been observed in coral grounds (Grehan *et al*., 2005). Longline fisheries also occur in canyon systems. Extensive evidence of lost lines has been seen in Whittard (Allcock, unpublished).

Extensive evidence of lost long-lines and other fishing gear has been seen in Whittard and other canyons on the Irish continental margin (Allcock, unpublished, see Figure 24). Huvenne *et al*. (2009) illustrate corals entangled in a lost long-line in Whittard. A survey of litter in deep-water habitats (Pham *et al*., 2014a, 2014b) found lost fishing gear to represent 25% of all litter in submarine canyons and nearly 75% on seamounts, banks and mounds. This reflects the attractiveness of these highly productive areas to fisheries and the difficult terrain. Structural damage and ghost fishing by lost gear in the strong currents are potentially serious issues.

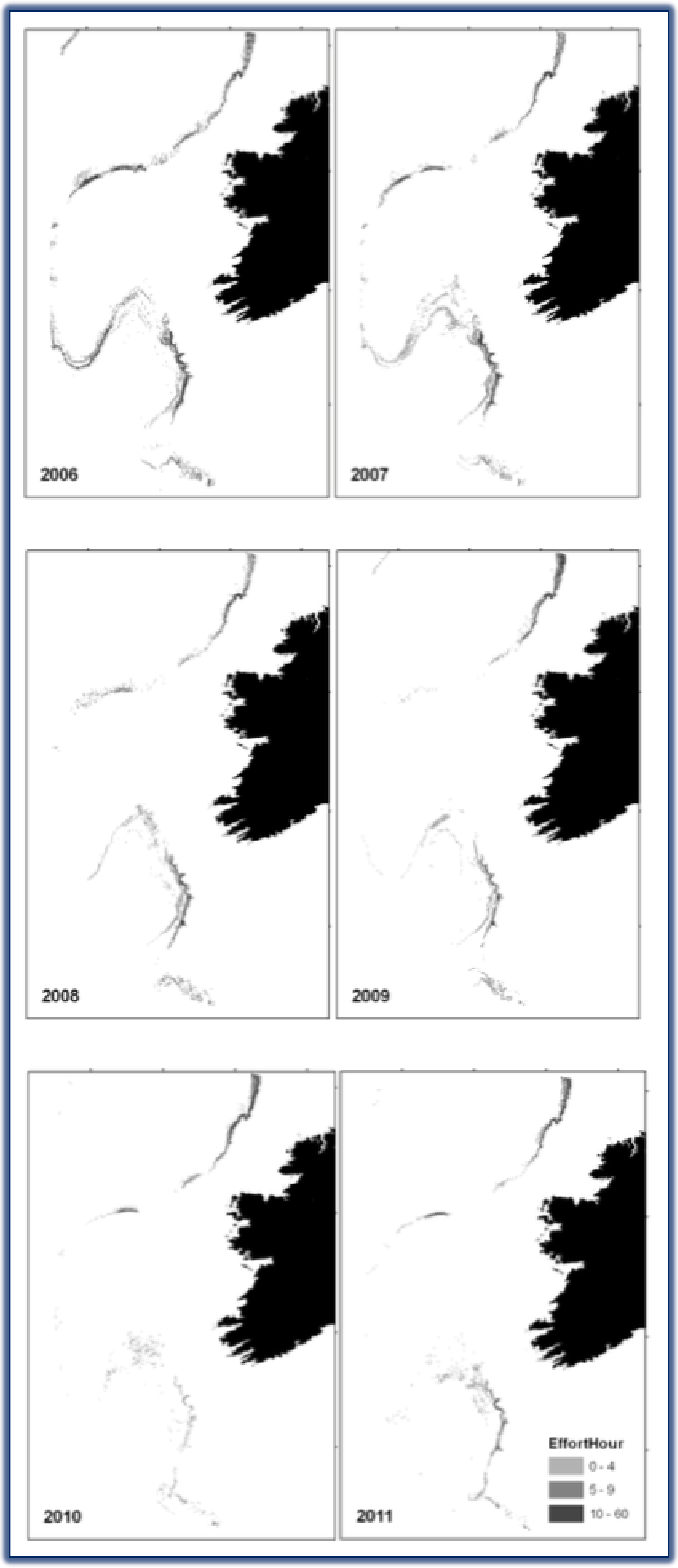


Figure 1 Map illustrating sampling locations at A, Logachev Mounds; B, Arc Mounds and C, Belgica Mounds (from CoralFISH, 2013).

3.2 Climate change

Climate change may alter offshore coral reef systems in at least two ways (Guinotte, 2006; Gruber *et al.,* 2023; Hennige *et al*., 2014, 2015; Morato *et al.,* 2020; Orr *et al*., 2005; Sweetman *et al.,* 2017; Turley *et al*., 2007). Firstly, rising water temperatures will affect current patterns by changing water column density and so affect internal wave generation, thereby modifying the supply of organic material to the predominantly filter-feeding structural corals. Secondly, changes in the aragonite saturation horizon will likely impact the ability of corals to synthesise skeletal elements.

Studies have demonstrated that the ocean is changing both chemically and physically as a result of the uptake of anthropogenic carbon dioxide (CO_2) (*e.g*. Gruber *et al.,* 2023; Morato *et al.,* 2020; Orr *et al*., 2005; Ridge & McKinley, 2021), which may affect deep-water coral distribution and growth (Guinotte, 2006; Sweetman *et al.,* 2017; Turley *et al*., 2007). The rapid rise in atmospheric CO_2 is not only causing ocean acidification, but warming. Studies examining the combined effects of warming and acidification, alongside other predicted stressors, are urgently needed to understand the significance of global climatic change on cold-water corals and other vulnerable marine ecosystems (Hennige *et al*., 2014). It is estimated that up to 70% of cold-water coral reefs, which currently live at low saturation states, will be in aragonite-undersaturated water by the end of the century due to the projected shallowing of the aragonite saturation horizon (Hennige *et al*., 2015).

McGrath *et al*. (2012) looked at inorganic carbon and pH levels in the Rockall Trough from 1991 to 2010. They estimated the aragonite saturation horizon to occur at about 2500 m in the Rockall Trough. While they were unable to draw conclusions on the changing saturation horizon in the Trough, due to a small number of data points collected below 2300 m in 2009/10, McGrath *et al*. (2012) expect a decrease in the depth of the aragonite saturation horizon in the North Atlantic, due to increasing anthropogenic CO_2 penetration. There has already been a 20% reduction in calcium carbonate saturation between 1766 and 2007. In the eastern North Atlantic, the aragonite saturation horizon has shallowed by 400 m since the industrial revolution, and is projected to decrease by 700 m by 2050. The aragonite saturation horizon in the nearby Iceland Sea is shallowing at a rate of 4 m/year. The observed reduction in aragonite and calcite saturation may have implications for calcifying organisms in the region, particularly cold-water corals along the Irish continental shelf, although further work is required to determine change in the aragonite saturation horizon in Irish waters.

In general, the impact of ocean acidification upon Scleractinian corals, both tropical and cold, seems to be inconsistent, with different species exhibiting negative, no measurable response, or variable responses to a change in conditions. This is further complicated by suggestions that corals may be more or less susceptible to ocean acidification depending upon their ontogenetic stage (Hennige *et al*., 2014). Short-term experimental data on the effects of increased CO_2, upon the metabolism of freshly collected *Lophelia pertusa* from the Mingulay Reef Complex, Scotland, and its comparison with net calcification rates indicated that *Lophelia pertusa* may be forced to use energetic reserves to maintain calcification rates. This is potentially detrimental in the longer term, as expending energetic reserves is a finite strategy (Hennige *et al.,* 2014).

Hennige *et al.* (2015) has shown that *Lophelia pertusa* can acclimatise to multiple stressors of temperature and CO_2, but that significant changes happen to its skeletal biomineralisation, molecular-scale bonding and structure, resulting in exposed coral framework, which forms the structural base of cold-water coral reefs, and it becomes structurally weaker, even after 12 months of high CO_2 conditions. Hennige *et al*. (2015) point out that it is premature to assume that the impacts of ocean acidification on cold-water corals will be negligible based solely on the ability of live coral to physiologically acclimatise in the short term, and that strategies to reduce CO_2 emissions are still needed to minimise impacts of ocean acidification on cold-water corals, as well as other marine biodiversity.

Soetaert *et al*. (2016) describe the presence of a 'topographically-enhanced carbon pump' where suitable biogenic and geological topographies occur. They speculate that climate change may negatively impact on the energy balance of cold-water corals, due to disruption of the topographically-enhanced carbon pump, by enhanced stratification and lower surface productivity. This has implications for the long-term management of biogenic reef SACs.

Some recent papers have discussed whether force majeure provisions can be invoked in European legislation if unfavourable environmental conditions ensue, such as sea level rise and temperature elevation, due to climate change (Elliott *et al*., 2015; Saul *et al*., 2016). Climate change is an exogenic, unmanaged pressure, in that it emanates from outside the area being managed, but in which the management authority has to respond to the consequences of climate change, rather than its causes (Saul *et al*., 2016).

3.3 Pollution/litter

Anthropogenic litter is present in all marine habitats, from beaches to the most remote points in the oceans. On the seafloor, marine litter, particularly plastic, can accumulate in high densities with deleterious consequences for its inhabitants (Pham *et al*., 2014a, b). Pham *et al.* (2014a, b) examined data from 588 video and trawl surveys across 32 sites in European waters. Litter was found to be present in the deepest areas and at locations far from land. The highest litter density occurred in submarine canyons, whilst the lowest density was found on continental shelves and on ocean ridges. Plastic was the most prevalent litter item found on the seafloor, while litter from fishing activities (derelict fishing lines and nets) was particularly common on seamounts, banks, mounds and ocean ridges.

A study undertaken as part of the European Commission CoralFISH project investigated litter at three mound provinces in Irish offshore waters: Logachev Mounds, Arc Mounds, and Belgica Mounds (see Figure 25) (CoralFISH, 2013). At each mound province, three area boxes in coral (on mound) and area boxes in non-coral (off mound) areas were randomly selected. Within each box a standardised 2 km long transect was surveyed using ROV mounted video. All encounters with lost fishing gear, suspected trawl tracks and items of rubbish were noted during the video surveys. In general, encounters providing evidence of anthropogenic impacts were low. The highest incidence of encounters was recorded for lost static gears in the Logachev Mounds. Remnants of both gill/tangle nets and long-lines (see Figure 26 a-f) were visible, which have been immersed for different durations, as shown by the degree of epifaunal fouling. Some displacement of corals was apparent where snagged nets have been dragged through and outside of reef areas (Figure 26 d).

While microplastics are increasingly recognised as a global problem, even in the deep sea (Woodall *et al*., 2014), there is, as yet, no information on microplastic load at Irish deep-water geogenic reefs. Microplastics have been found ingested by deep-sea corals (Taylor *et al*., 2016), but the likely impacts of such ingestion remain unknown. Given the increased flow in submarine canyons it is possible that they might act to concentrate microplastics.

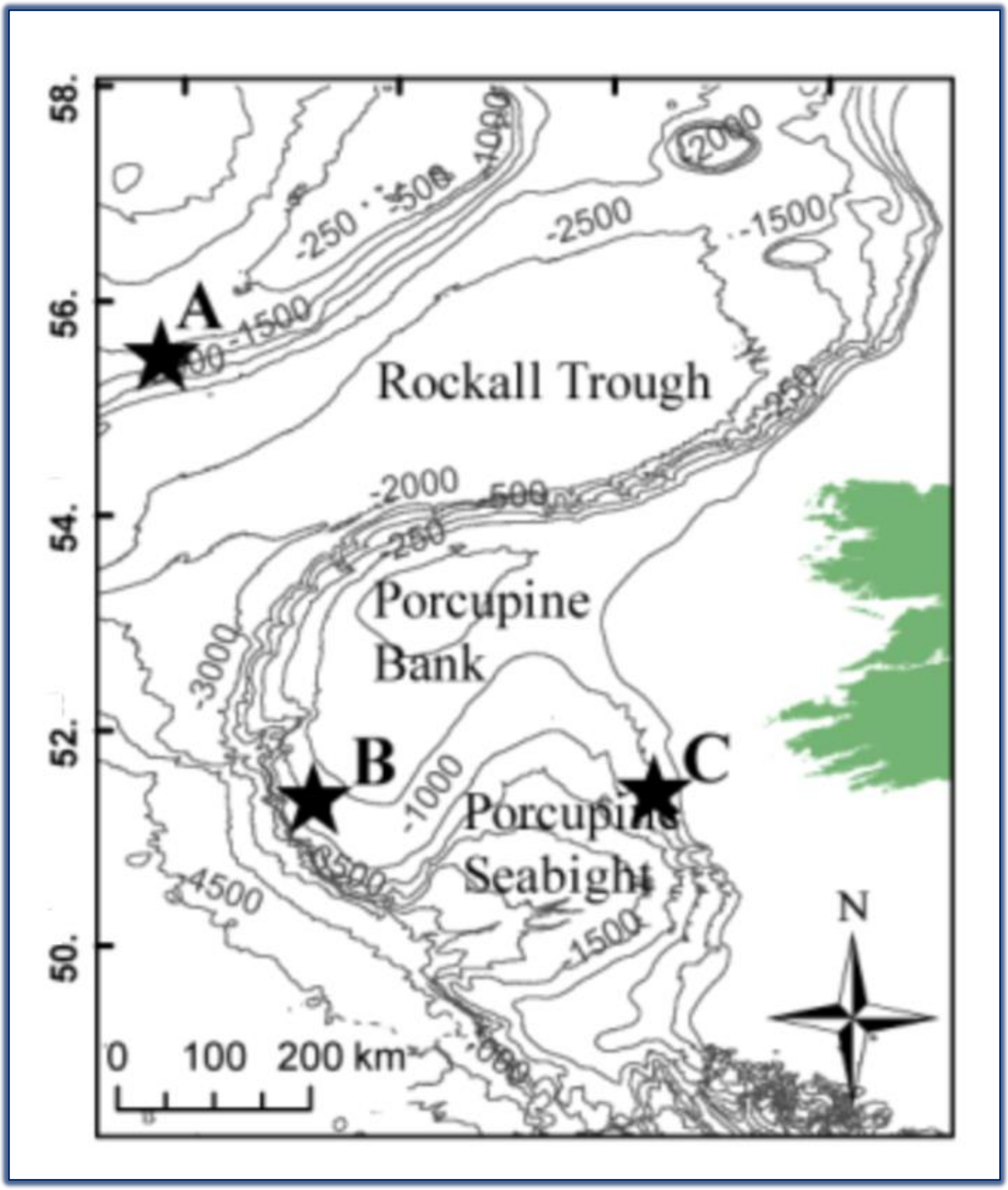


Figure 2 Map illustrating sampling locations at A, Logachev Mounds; B, Arc Mounds and C, Belgica Mounds (from CoralFISH, 2013).

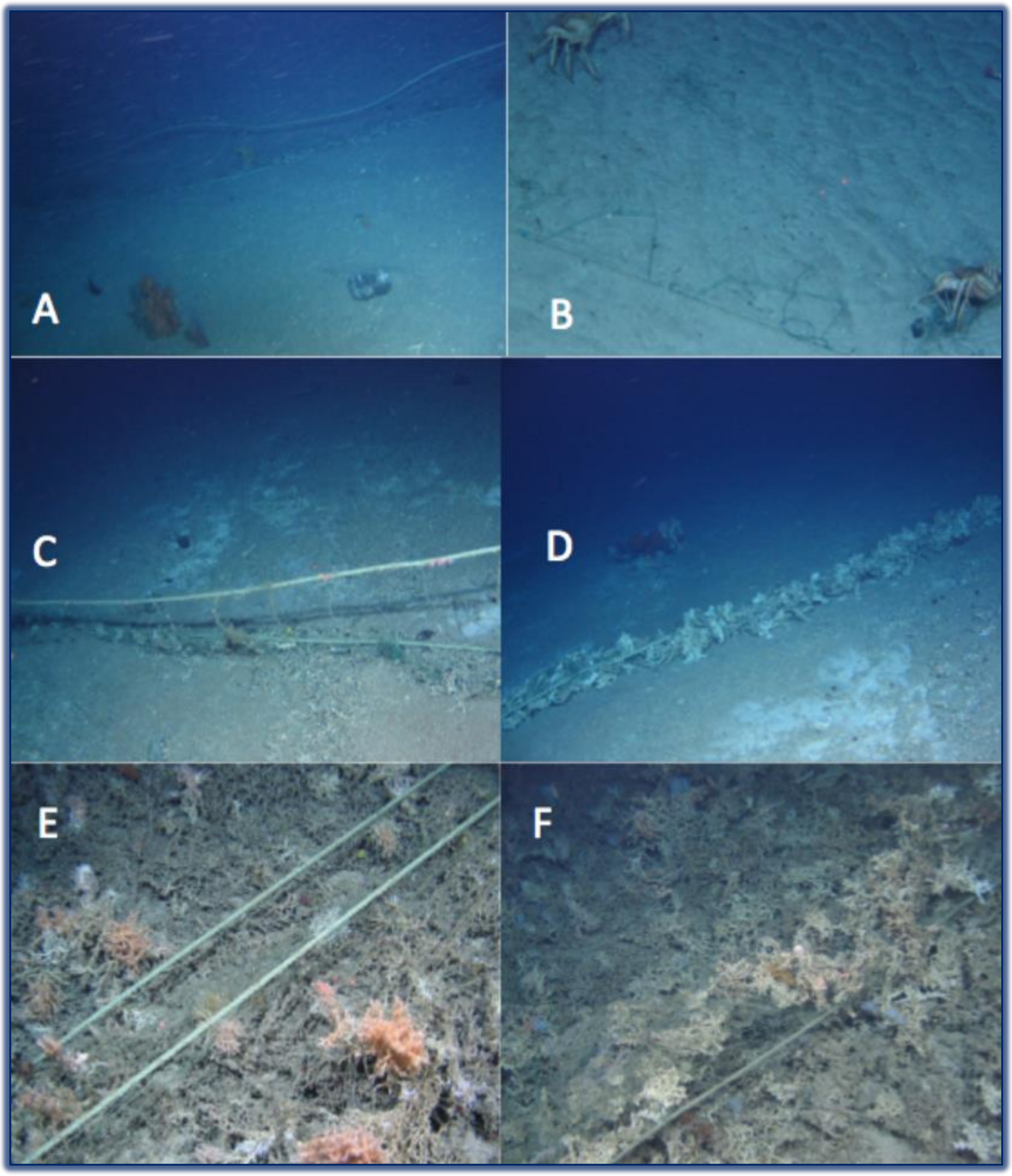


Figure 3 Examples of lost fishing gear, suspected trawl tracks and items of rubbish at carbonate mound habitats (from EC CoralFISH project).

3.4 Mining, extraction of materials and energy production

The Irish Offshore Operators Association (IOOA) held a workshop on the ‘Cold-water corals and offshore hydrocarbon operations on the Irish Atlantic Margin’ in December, 2014. The ensuing report (IOOA, 2015) outlined the current state of knowledge of cold-water corals in Irish waters and the potential interactions from petroleum exploration. There was a clear consensus and understanding that whilst there is a knowledge gap in the exact distribution of coral reef across the area, there is a reasonable understanding of the processes which drive cold-water corals distribution and the interaction of anthropogenic activities.

3.4.1 Seismic surveys

Discussion of the potential interaction of planned seismic activities focused predominantly on the impact of sound pressure waves on coral polyps, cold-water coral reef, and in particular *Lophelia pertusa*, and associated species. A number of other planned and unplanned events were also discussed (*e.g*. loss of acoustic gear), however, given the depth of cold-water coral, the potential for significant interaction with reef habitats and associated species was assessed as low and the potential likelihood (emergency events such as ship loss) was deemed extremely unlikely.

The key conclusions were:

- In a study investigating potential impacts of seismic sound on tropical coral at Scott Reef, Australia (water depths of 15 m – 30 m) Hastings *et al*. (2008) gave evidence to support the findings of no significant or adverse effects of seismic sound pressure on tropical coral communities and associated species.
- Based on acoustic modelling by Austin *et al*. (2014) sound levels at the seabed from a typically large seismic survey received at cold-water coral provinces in the Porcupine Basin conformed to the NPWS Guidance Low Energy State recommendations and are below levels that would cause physical damage to corals (Hastings *et al*., 2008).
- In general, spawning in *Lophelia pertusa* occurs in January and February (Larsson *et al*., 2014) with larval stages remaining in the water column for up to 30 days before settling as juveniles. Given that in Irish waters seismic survey activities are typically conducted between April and September, potential interaction with cold-water coral reef planktonic larval stages is highly unlikely.
- Discussion concluded that it is highly improbable that seismic survey interaction with Irish cold-water coral and reef-associated species would cause short- or long-term adverse biological impacts. This conclusion was based on potential peak levels of sound received at cold-water coral reefs (Austin *et al*., 2014) being below thresholds for behavioural and physical impacts reported for tropical coral (Hastings *et al*., 2008) and fish species (Popper *et al*., 2014).
- Other species typically associated with Irish cold-water coral are also unlikely to be affected, as modelled sound levels received at the seabed are significantly below levels reported in Battershill *et al*. (2008), which indicated no significant impact of sound on benthic communities. Similarly, based on the findings of Andriguetto-Filho *et al*. (2005), and sound levels modelled for Irish cold-water coral, impact on invertebrates such as shrimp species were deemed unlikely.

3.4.2 Drilling operations

The discussion of the drilling interactions covered various management and mitigation controls, and examples whereby potential interaction or impacts on cold-water coral reef could be eliminated. These management and mitigation approaches fall into two broad categories:

I. Avoidance – primarily to undertake all drilling operations and discharges at a distance or vector to ensure no potential interactions between drilling operations and cold-water coral reef.

II. Engineering – the conclusion of the drilling workshop session was that there are numerous engineering solutions to avoid interactions with cold-water coral reefs which have been used effectively in other European jurisdictions, including the Norwegian Continental Shelf.

Both of these approaches require:

- Site Survey to produce high resolution mapping and condition of cold-water coral reef within the drill site area (*e.g*. Multibeam Echo Sounder, Side Scan Sonar, Sub Bottom Profiler, and ROV/camera);
- Modelling of the dispersion of routine drilling operation discharges (*e.g*. drill cuttings). Modelling would require determination analysis of major or prevailing bottom-boundary, sub-surface and sea surface currents;
- Identification of impact thresholds of cold-water coral based on evidence from laboratory and field studies, to support management approaches and agreed industry guidelines (Ulfsnes *et al*., 2015); and
- Appropriate monitoring programmes to validate modelling predictions, impact threshold and assessments (Ulfsnes *et al*., 2015).

It was noted that the extensive hydrographic and coral recruitment baseline studies completed at Scott Reef, Australia, in the 15 years prior to drilling the Toroas 6 appraisal well, were extremely valuable in defining the connectivity and coral recruitment dependence between regionally emergent tropical coral atolls. Based on this work, it was considered that the collection and analysis of bottom boundary and sea surface currents may facilitate an assessment of connectivity between cold-water coral reef systems on the Atlantic margin.

4 Management and indicators

This section provides summary information of some tools that could be applied to assist in the development and management of coral marine protected areas in the Irish offshore.

4.1 Marine protected areas and indicators

The FP6 project PROTECT developed some practical tools for planning and evaluation of marine protected areas that could be applied to manage coral SACs in the Irish offshore (PROTECT, 2009). Marine protected areas are established for a wide range of purposes and there are different considerations involved in determining to what extent a given area is reaching its predetermined goals. To evaluate performance against a predefined goal, specific and measurable objectives must be defined in terms of what outputs and outcomes are expected. This in turn requires well-defined management plans, pre-defined criteria for success, and monitoring of the impact of management actions. The results of these activities should be fed back into the planning process for identifying marine protected areas with possible revision of objectives, plans and outcomes *i.e*., adaptive management (PROTECT, 2009) (see Figure 27).

The development of goals and objectives is an integral part of planning marine protected areas. In 2000, the International Union for Conservation of Nature (IUCN) together with the World Wide Fund for Nature (WWF) identified the main objectives with regard the management of marine protected areas:

- To develop a set of natural and socio-economic indicators to evaluate marine protected area management effectiveness;
- To develop a process for conducting a marine protected area evaluation – in the form of an easy-to-use guidebook;
- To ground-truth and field-test the guidebook and indicator methods; and
- To encourage uptake.

The programme conducted a review of goals and objectives for marine protected areas from around the world, and categorised these into three broad types:

- Biophysical,
- Socio-economic; and
- Governance.

A range of indicators (or indices) to assess achievement of these goals and objectives were identified. Operational descriptions and definitions were subsequently provided for the indicators as well as a detailed narrative of methods of measurement and guidance on analysis and interpretation of results. The guidebook was published in 2004, in collaboration with WWF, IUCN and the US National Oceanic and Atmospheric Administration (NOAA) (Parks *et al.,* 2004).

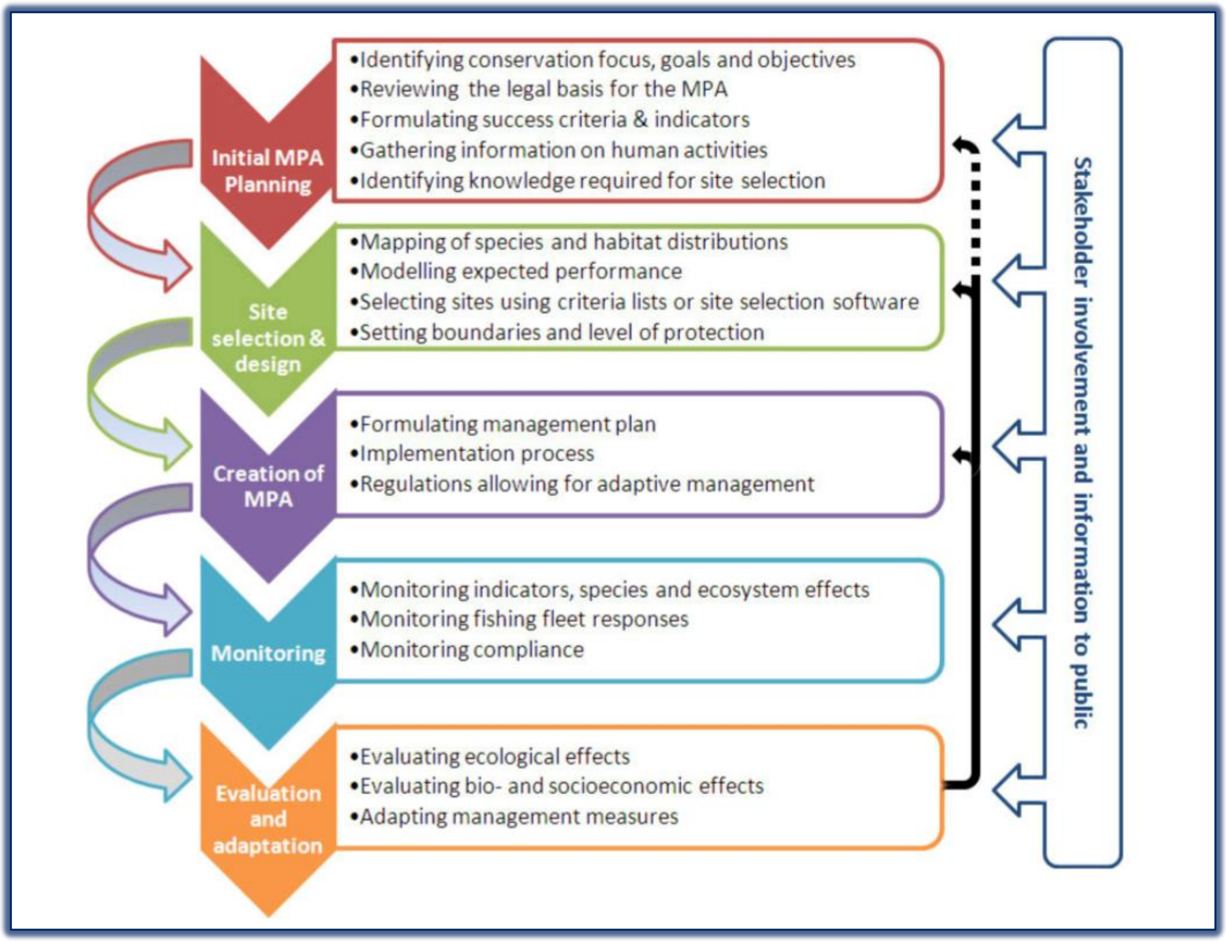


Figure 27 The PROTECT planning framework for developing and managing marine protected areas (from PROTECT, 2009).

4.2 Risk-based management of fisheries impacts

As part of the FP7 CoralFISH project, a risk-based approach was developed, to manage the potential interactions between fishing activity and vulnerable marine ecosystems (VMEs) (including cold-water coral reef) in the Irish offshore (CoralFISH, 2013). As part of the risk-based approach, areas of interaction were identified based on the distribution of fishing activity (see Figure 27 above) within areas of known and predicted coral habitat (see Figure 28). Areas of interactions were then assigned to a relative risk category based on certainty of the occurrence of coral habitat, with areas of known coral habitat identified as high risk and areas of predicted coral presence identified as low risk. The spatial distribution of risk, shown in Figures 29 and 30, then forms the basis for the recommendation of fisheries management actions (see CoralFISH [2013] for description of management actions).

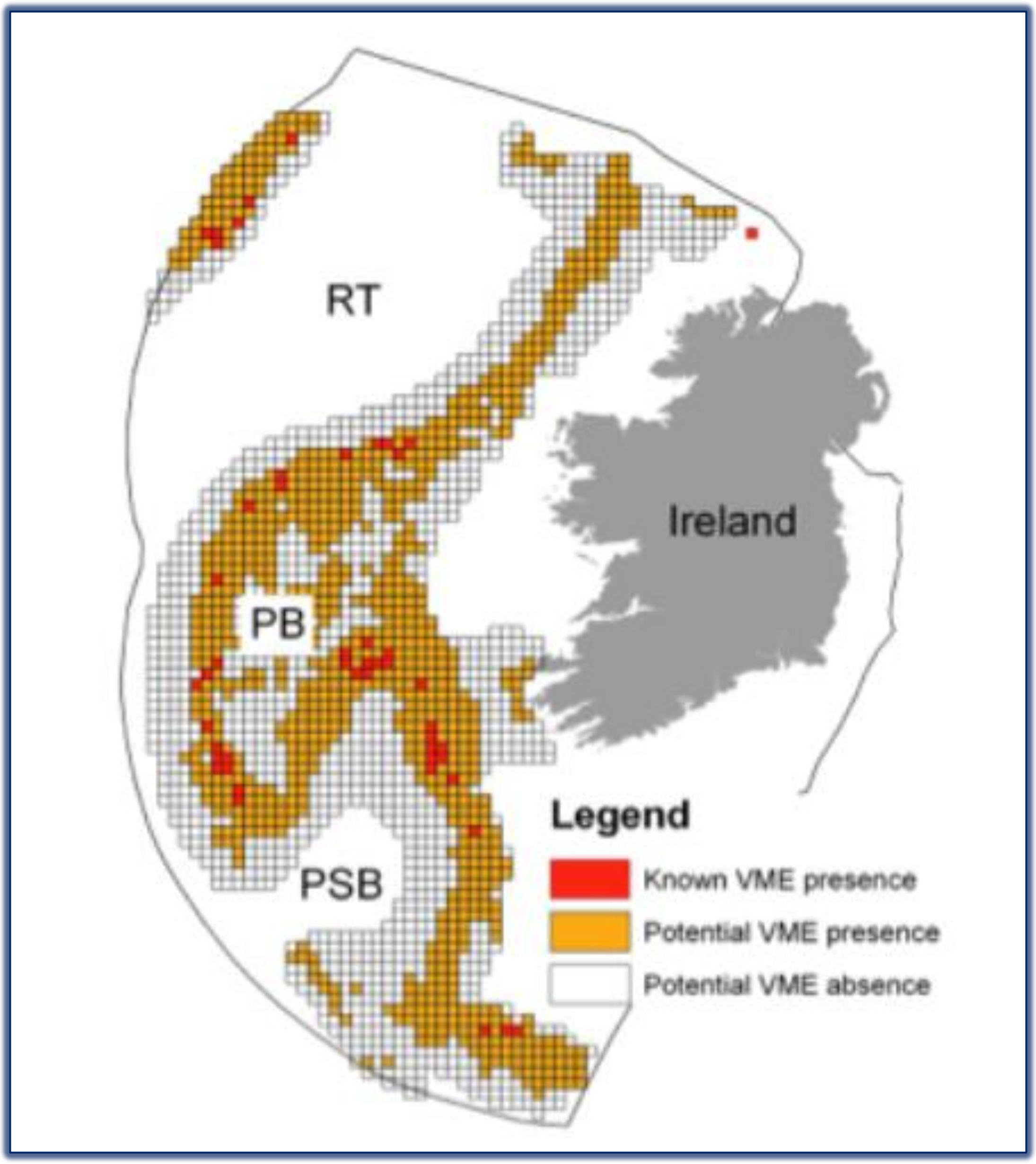


Figure 28 The known, predicted presence and absence of vulnerable marine ecosystems (VMEs) (i.e., cold-water coral reefs) in Irish waters mapped onto a 10 x 10km grid. Predicted coral reef distribution is based on the output from the NUIG high resolution coral reef habitat suitability model (Rengstorf *et al*., 2013; CoralFISH, 2013).

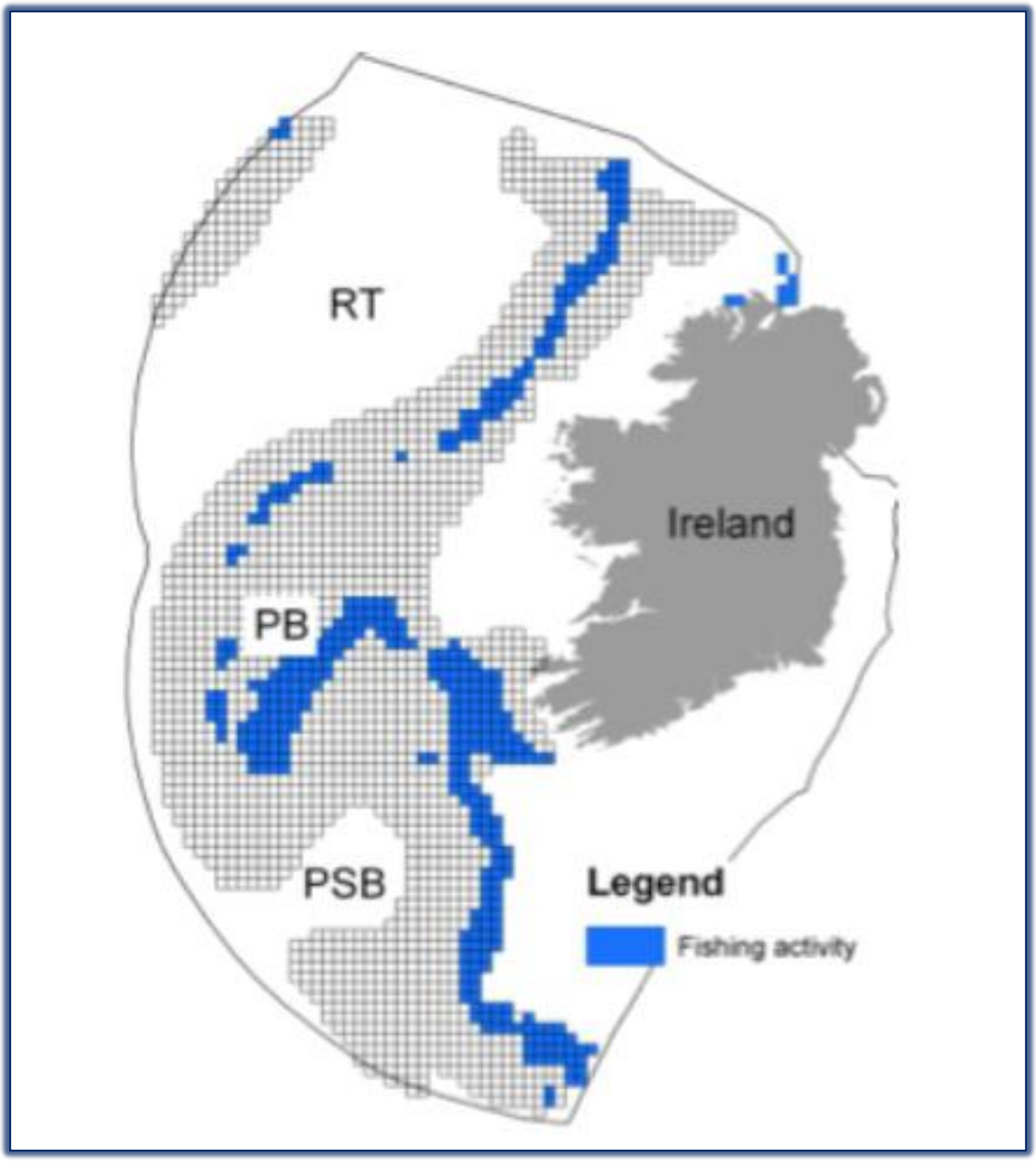


Figure 29 The distribution of fishing activity off the Irish west coast derived from analysis of VMS records from the British fishing fleet (CoralFISH, 2013).

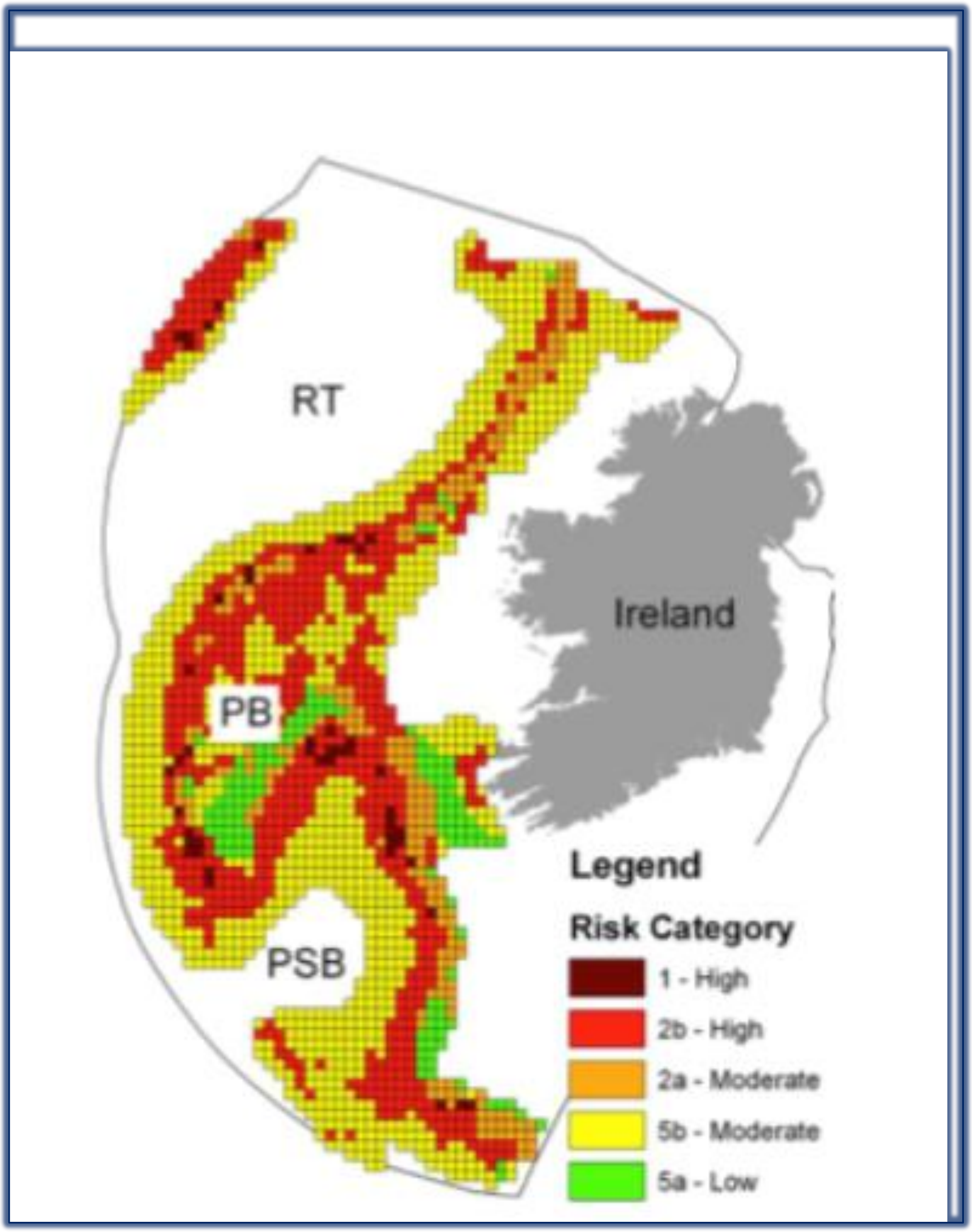


Figure 30 Map showing assigned risk category (from CoralFISH, 2013).

5 Policy influencing the protection and conservation status

5.1 Maritime Spatial Planning Directive

The Maritime Spatial Planning (or Marine Spatial Planning) (MSP) Directive (2014/89/EU) (Council Directive, 2014) is a '*… cross-cutting tool enabling public authorities and stakeholders to apply a coordinated, integrated, and transboundary approach. The application of an ecosystem-based approach will contribute to promoting the sustainable development and growth of the maritime and coastal economies and the sustainable use of marine and coastal resources'*.

In Ireland, the competent authority is the Department of Housing, Local Government and Heritage. The regulation was transposed into Irish law on September 18th, 2016. Under the provisions of the Directive, Ireland was required to develop and implement a national Marine Spatial Plan. On the 1st of July 2021, Ireland's Marine Spatial Plan, called the National Marine Planning Framework (NMPF), was formally launched. The NMPF covers all marine-based, human activities and outlines objectives and marine planning policies for each marine activity. The NMPF details how these marine activities will interact with each other in an ocean space that is under increasing spatial pressure, ensuring the sustainable use of Ireland's marine resources to 2040. The NMPF is intended as the marine equivalent to the National Planning Framework and has been prepared with an ecosystem-based approach, informed by best available knowledge. Legislation of particular relevance that is integrated into the NMPF includes;

- The Habitats Directive (see Section 5.2),
- The Environmental Impact Assessment (EIA) Directive (see Section 5.3),
- The Strategic Environmental Assessment (SEA) Directive (see Section 5.4); and
- The Marine Strategy Framework Directive (MSFD) (see Section 5.5).

5.2 Habitats Directive

The Habitats Directive provides legal protection for habitats and species of European importance. In particular, Articles 3 to 9 provide the legislative means to protect habitats and species of European importance through the establishment of SACs. To date, Ireland has designated forty-eight SACs for the protection of Annex I Reef habitat within Irish waters, of which eight are offshore sites. The establishment of SACs includes the establishment of objectives or targets, or management plans to ensure the protection of qualifying feature(s) for which the site is designated. In the case of Ireland's offshore SACs, six of the eight sites have site-specific objectives established, with the two most recently designated sites (Porcupine Shelf SAC and Southern Canyons SAC, designated in 2023) yet to have site-specific objectives published. A list of the offshore reef SACs and their extent is provided in Appendix B (Table 4). In recent years, significant levels of survey work have been undertaken to investigate the structure, distribution and extent of these reef habitats in Irish SACs.

Article (6)3 of the Habitats Directive establishes the requirement that any plan or project not directly connected with or necessary to the management of a SAC site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives. A plan or project will only be permitted where significant adverse impacts to the site concerned can be ruled out. In the case where negative impacts cannot be ruled out and in the absence of alternative solutions, the plan or project will only be permitted where it can be shown that imperative reasons of overriding public interest exist.

5.3 Environmental Impact Directive

The EIA Directive (85/337/EEC as amended 2011) (Council Directive, 1985) is recognised as a central tool for environmental management. It is an important mechanism for facilitation of improved stakeholder awareness and improved levels of environmental accountability (Barker & Jones, 2013). Implementation of EIA as an instrument to protect the environment was initially brought into force through the European Council (EC) Directive 85/337/EEC and has since been amended by EC Directives 97/11/EC, 2003/35/EC and 2009/31/EC (Council Directive, 2009), all of which are codified within Directive 2011/92/EU of 13th December 2011. The EC then proposed additional amendments to the Directive (European Commission, 2013) having the objective of adjusting the codified EIA Directive to correct shortcomings, reflect on-going environmental and socio-economic changes and challenges, and align with the principles of Smart Regulation (2014/52/EU).

The Directive's main aim is to ensure that any project, which is likely to have significant impact (positive or negative) on the environment by virtue, *inter alia*, of its size, nature or location is subject to a full assessment of effects upon the natural and human environment. "Significance" of potential impacts is determined through a risk assessment process, assessing both the consequence of an impact and the likelihood that risk will be realised. The EIA process aims to facilitate the best possible environmental outcome from a proposed project and to provide as much information as possible for the regulator/consenting authority to perform an informed judgement as to whether or not the project should be given development consent. Thus, EIA facilitates a more informed decision making process, helping to result in the avoidance or reduction of adverse environmental effects (DECLG, 2013).

5.4 Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) (2008/56/EC) (Council Directive, 2008) is a major piece of EU legislation that requires Member States to adopt an ecosystem-based approach to the management of human activities and the marine environment. The Directive provides an overarching framework for European legislation (including the Habitats Directive). Under the Directive, Member States were required to conduct an Initial Assessment of their marine environment and to establish a suite of environmental targets and measures to achieve Good Environmental Status of their marine waters by 2020. The Department of Housing, Local Government and Heritage (DHLGH) is the lead body for the implementation of the MSFD and progress to date includes the initial assessment describing the 2012 status of Ireland's marine environment, and a further updated assessment in June 2020.

Ireland's MSFD 2020 Assessment reported that offshore circalittoral rock and biogenic reef habitat occupies 3,381 km^2 of sea-floor in the Irish segment of Region III, within which 72% was assessed as highly disturbed. It was also reported that due to limitations around data accuracy and availability, the assessment of physical disturbance could not be extended to the entire Irish maritime area. As part of the on-going MSFD process Ireland is developing targets and indicator of habitat condition for offshore habitats and the continuing efforts relating to the establishment of offshore marine protected areas.

5.5 Strategic Environmental Assessment

The Strategic Environmental Assessment (SEA) Directive (2001/42/EC) (Council Directive, 2001) applies to a wide range of national public plans and programmes which in the offshore includes fisheries, energy, industry, transport, waste and water management, and telecommunications. Broadly speaking, the first step in the SEA process involves undertaking a screening assessment (based on criteria set out in Annex II of the Directive) to determine whether the plans/programmes are likely to have significant environmental effects. If there are significant effects, an SEA is needed. The SEA procedure includes the preparation of an environmental report in which the likely significant effects on the environment and the reasonable alternatives of the proposed plan or programme are identified. The public and the environmental authorities are informed and consulted on the draft plan or programme and the environmental report prepared.

Under the provisions of the SEA Directive the Irish Department of Environment, Climate and Communications has undertaken a series of national regional environmental assessments (IOSEA 1 – IOSEA5) to underpin hydrocarbon exploration activities. As part of the SEA process, potential effects to offshore reef habitats and associated communities were considered. In addition to undertaking SEAs for Ireland's offshore hydrocarbon exploration and exploitation activities, the department is responsible for the promotion, regulation and monitoring of the exploration and development of the industry. In order to ensure that industry activities are conducted with due regard to their impact on the environment, operators must submit an application for approval to commence activities. As part of the application process operators must undertake environmental assessments that meet the requirements of the Habitats Directive (see Section 5.2 above) and EIA Directive (see Section 5.3).

5.6 EU Deep Sea Access Regime

The EU Deep Sea Access Regime regulates which kind of operators are allowed to target deep-sea species and sets the conditions under which Member States can issue licences for deep-sea fisheries. A major review of the Regime took place in 2016. On 30 June 2016 the Council and the European Parliament agreed on revised rules for the fishing of deep sea species in EU waters (EU Regulation 2016/2336). The regulation aimed to ensure the sustainable exploitation of deep sea stocks while reducing the environmental impact of these fisheries. On 15 September 2022, the EC adopted an implementing act closing 87 areas to all bottom fishing gears which represents 17% of the area between 400-800 metres depth of EU waters of the North-East Atlantic and 1.16% of the EU waters of the North-East Atlantic. The total area of the closures is 16,419 km^2 reserved for the protection of vulnerable marine ecosystems below 400 metres (EU Regulation 2022/1614). The regulation also sets a geographical footprint based on historical criteria by which vessels will only be able to fish in those areas where they have done so during the reference period. This regulation aims to reduce the potential fishing impacts on cold-water coral habitats in Irish waters.

6 Knowledge gaps and recommendations

6.1 Conservation initiatives: Additional SAC's

Rengstorf *et al*. (2013) developed a high resolution habitat suitability model for *Lophelia* reefs using a quality controlled, geo-referenced, coral reef presence database and terrain attributes, generated from analyses of the Irish National Seabed Survey bathymetry (see Figure 17). This model was used to predict the distribution of *Lophelia* in Irish waters in order to demonstrate the utility of high-resolution habitat suitability models in conservation planning by assessing the representativeness of the initial conservation initiatives to protect biogenic reef.

Ross (2016) investigated the development of an 'ecologically coherent' network of deep-sea marine protected areas using larval dispersal models. It was found that the Irish marine protected area network may be improved in terms of connectivity between protected areas. Ross (2016) reported that the huge area of Irish continental shelf, which at the time of publication was unprotected (see Figure 31), would benefit from further protection, particularly between Porcupine Bank, the Barra Fan, and Hebrides Slope in UK waters. This agrees with recommendations made by Rengstorf *et al*. (2013) derived from their high resolution *Lophelia pertusa* reef model. In 2023, a new offshore marine SAC was designated in this area; the Porcupine Shelf cSAC (Site code: 002267), which is designated for Reef habitat (1170). This site supports cold-water coral species (*Desmophyllum pertusum* [syn. *Lophelia pertusa*] and *Madrepora oculata*) at numerous locations (NPWS, 2023a).

It had been suggested that the Goban Spur would also be a useful area for future protection in order to better connect The Canyons Marine Conservation Zone (a protected area under UK jurisdiction) to the Irish network. Rengstorf *et al*. (2013) recommended the Whittard Canyon, which is near this region, as an alternative area for designation but indicated that the complex topography of canyon features may be more conducive to larval retention than larval exchange. In 2023, a new marine offshore SAC was designated in this area; the Southern Canyons cSAC (Site code: 002278), which is designated for Reef habitat (1170). The southernmost extent of Rockall Bank may also be a good area for protection in the future, providing support to the Logachev mounds as a stepping stone for larvae transiting both in the Rockall Trough and the southern Hatton Rockall Basin.

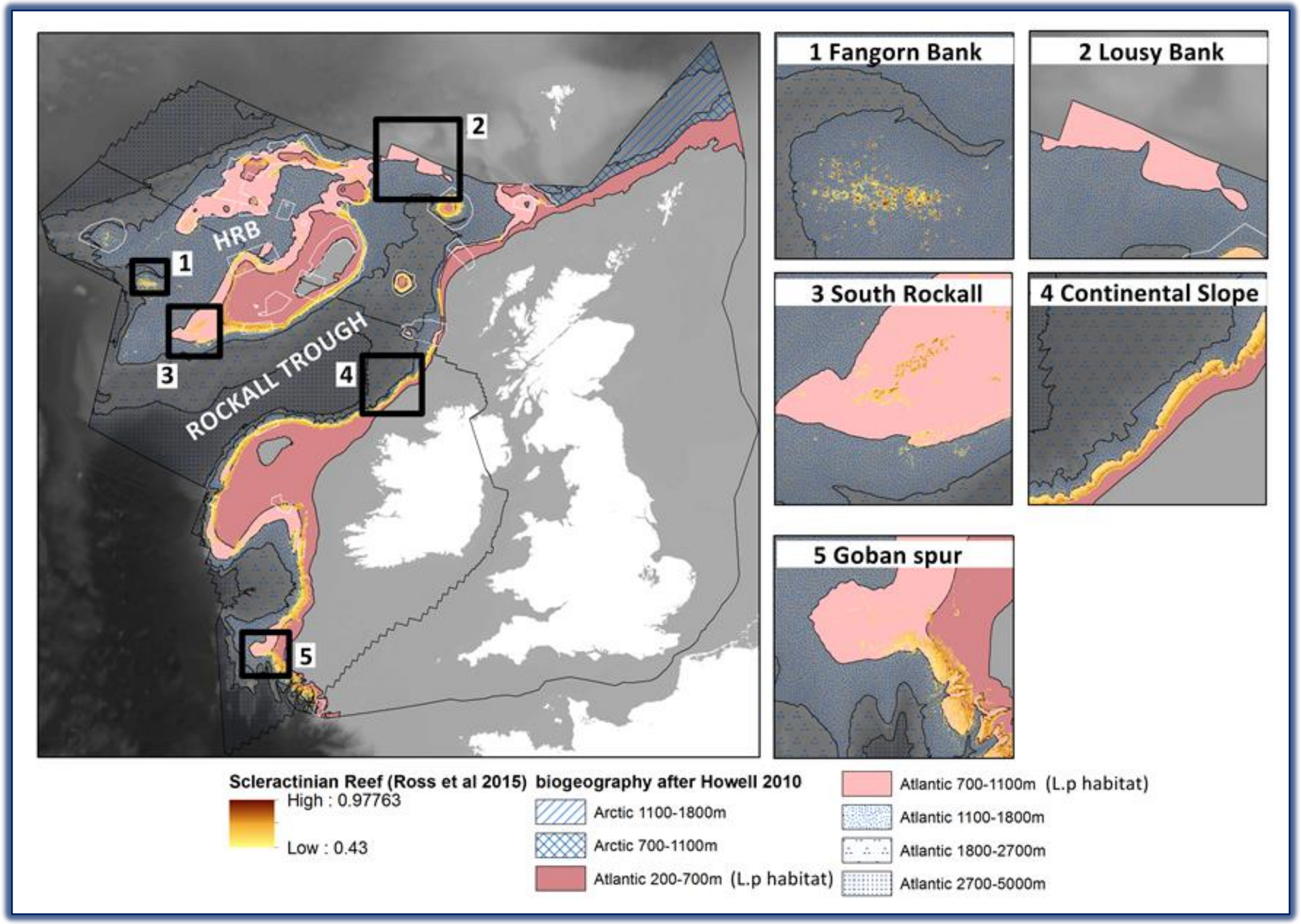


Figure 31 Habitat suitable for *Lophelia pertusa* species and Scleractinian reef (from Ross *et al*., 2015): *Lophelia pertusa* reef < 1,100m, *Solenosmilia variabilis* reef > 1,100 m), biogeography after Howell (2010). Also shows the maximum area currently protected and helps to identify areas where future protection may be beneficial (Ross, 2016). HRB; Hatton Rockall Basin

6.2 Areas of future study

6.2.1 Extent and range

In recent years, significant levels of survey work have been undertaken to investigate the distribution and extent of offshore reef habitats in Irish waters; an extensive offshore reef survey of Ireland's continental slope was commissioned by the Marine Institute in partnership with the NPWS, funded by the European Maritime and Fisheries Fund (EMFF), and coordinated and led by INFOMAR. The Sensitive Ecosystem Assessment and ROV Exploration of Reef (SeaRover) survey took place between 2017 to 2019 (O'Sullivan *et al.,* 2018, 2019). This survey covered 0.91km^2 of Ireland's continental slope, representing 0.00096% of the total area of Ireland's continental slope, highlighting a need for further surveying effort. There are more than 50 canyon systems on the Irish continental margin. Depending on topology, these may likely harbour geogenic reef. Local scale species distribution modelling could help to determine which of these areas are likely to encompass significant geogenic reef.

6.2.2 Taxonomic studies

Although there is ongoing work in this area, and there has been major progress in recent years, many structure-forming species are still only identified to genus. In part, this reflects a global emphasis on updating and revising the systematics of these difficult groups. It is important that Ireland be part of these studies in order to benefit from global taxonomic expertise.

6.2.3 Genetic connectivity of marine protected areas

The understanding of connectivity between *Lophelia pertusa* reefs would benefit from combining genetic data with hydrodynamic modelling of larval dispersal. Information about time of spawning, larval swimming behaviour, time spent in the plankton (competency periods and longevity), and mortality rates are crucial inputs for the development of robust models (Hilário *et al*., 2015).

6.2.4. Biotope classification

The CoralFISH project (CoralFISH 2013) produced a detailed description of the different cold-water coral habitat types encountered in European seas, including off the west coast of Ireland. The cold-water coral catalogue is intended to be dynamic (easily expandable) and includes the location and depth range of cold-water coral habitats mapped during the project. A total of 74 distinct cold-water coral biotopes are recognised. Picton *et al.,* (2021) identified 139 biotopes and potential biotopes during the SeaRover surveys, in line with the Marine Habitat Classification for Britain and Ireland (JNCC, 2015). The MHCBI classification scheme has been further updated since then, with the addition of five new biotopes and revision of some existing biotopes in the Sublittoral Sediment section of the classification (JNCC, 2023). It is recommended that all Irish coral records be available to the National Biodiversity Centre.

6.2.5 Ecological studies

Understanding the resilience of communities to damage is integral to conservation planning. Knowledge of the age and growth, and of the reproductive strategies, of structure-forming species of the black coral genera *Trissopathes, Bathypathes, Stauropathes,* and *Leiopathes* and the Alcyonacean genera *Paragorgia*, *Paramuricea*, *Primnoa*, *Isidella*, *Keratoisis*, *Jasonisis* and *Lepidisis* are lacking for the eastern Atlantic. These genera encompass the dominant structure-forming species in Irish waters and should be the focus of future work.

6.2.6 Frequency and effects of sedimentation load

Increased sedimentation load associated with trawling activity on interfluves has been noted in Whittard Canyon (Wilson *et al*., 2015). It is known that black corals are particularly sensitive to sedimentation. Current gaps in knowledge include how frequently these increased sediment loads are being produced, and what the direct impacts of these loads might be on the black coral communities.

6.2.7 Water chemistry

Knowledge of the current water chemistry could provide a baseline against which to determine the severity of ocean acidification and the impact on the aragonite saturation horizon (see Section 2.4.1 above).

7 References

Addamo, A.M., Vertino, A., Stolarski, J., García-Jiménez, R., Taviani, M. & Machordom, A., (2016). Merging scleractinian genera: the overwhelming genetic similarity between solitary *Desmophyllum* and colonial *Lophelia*. *BMC Evolutionary Biology,* **16**(1), 1-17.

Allcock, A.L., Hogan, R., Wirth, M., La Bianca, G. & White, M. (2016). Black corals of the Whittard Canyon. Poster presented at 2016 Challenger Society Conference, Liverpool John Moores University.

Althaus, F., Williams, A., Schlacher, T., Kloser, R., Green, M., Barker, B., Bax, N., Brodie, P. & Schlacher-Hoenlinger, M. (2009). Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. *Marine Ecology Progress Series,* **397**, 279–294.

Amaro, T., Huvenne, V.A.I., Allcock, A.L., Aslam, T., Davies, J.S., Danovaro, R., De Stigter, H.C., Duineveld, G.C.A., Gambi, C., Gooday, A.J., Gunton, L.M., Hall, R., Howell, K.L., Ingels, J., Kiriakoulakis, K., Kershaw, C.E., Lavaleye, M.S.S., Robert, K., Stewart, H., Van Rooij, D., White, M. & Wilson, A.M. (2016). The Whittard Canyon – a case study of submarine canyon processes, *Progress in Oceanography,* **146**, 38-57.

Andrews, A.H., Stoner, R.P., Lundstrom, C.C. & DeVogelaere, A.P. (2009). Growth rate and age determination of bamboo corals from the northeastern Pacific Ocean using refined ^{210}Pb dating. *Marine Ecology Progress Series,* **397**, 173–185.

Andriguetto-Filho, J.M., Ostrensky, A., Pie, M.R., Silva, U.A. & Boeger, W.A. (2005). Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. *Continental Shelf Research,* **25**, 1720–1727.

Austin, M., McPherson, C., O'Neill, C., Warner, G. & Zeddies, D. (2014). Impacts of Seismic Surveys near Coldwater Coral Carbonate Mounds: Acoustic Modelling Study – Offshore Ireland, JASCO Document 00889, Version 1.0. Technical report by JASCO Applied Sciences for Woodside Energy (Ireland) Pty Ltd.

Battershill, C., Cappo, M., Colquhoun, J., Cripps, E., Jorgensen, D., McCorry, D., Stowar, M. & Venables, W. (2008). Coral Damage Monitoring using Towed Video (TVA) and Photo Quadrat Assessments (PQA) - Final Report: Towed Video and Photo Quadrat Assessments. MAXIMA 3D Marine Seismic Survey, Scott Reef, Report prepared by Australian Institute of Marine Science, Townsville for ERM and Woodside Energy.

Barker, A. & Jones, C. (2013). A critique of the performance of EIA within the offshore oil and gas sector. *Environmental Impact Assessment Review*, **43**, 31-39.Beazley, L. (2011). Reproductive biology of the deep-water gorgonian coral *Acanella arbuscula* from the Northwest Atlantic. MSc Thesis, Dalhousie University, Halifax, Nova Scotia http://hdl.handle.net/10222/13265]Accessed October 2020.

Bell, N. & Smith, J. (1999). Coral growing on North Sea oil rigs. *Nature,* **402**, 601–601.

Biber, M.F., Duineveld, G.C.A., Lavaleye, M.S.S., Davies, A.J., Bergman, M.J.N. & van den Beld, I.M.J. (2014). Investigating the association of fish abundance and biomass with cold-water corals in the deep Northeast Atlantic Ocean using a generalised linear modelling approach. *Deep Sea Research II,* **99**, 134–145.

Billett, D.S.M., Lampitt, R.S., Rice, A.L. & Mantoura, R.F.C. (1983). Seasonal sedimentation of phytoplankton to the deep-sea benthos: *Nature,* **302**, 520–522.

Bo, M., Di Camillo, C.G., Addamo, A.M., Valisano, L. & Bavestrello, G. (2009). Growth strategies of whip black corals (Cnidaria: Antipatharia) in the Bunaken Marine Park (Celebes Sea, Indonesia). *Biodiversity Records,* **2**, 54.

Bower, A.S., Le Cann, B., Rossby, T., Zenk, W., Gould, J., Speer, K., Richardson, P.L., Prater, M.D. & Zhang, H.M. (2002). Directly measured mid-depth circulation in the northeastern North Atlantic Ocean. *Nature,* **419**, 603–607.

Buhl-Mortensen, L. & Mortensen, P. (2004). Symbiosis in deep-water corals. *Symbiosis,* **37**, 33–61.

Buhl-Mortensen, L., Vanreusel, A., Gooday, A.J., Levin, L.A., Priede, I.G., Buhl-Mortensen, P., Gheerardyn, H., King, N.J. & Raes, M. (2010). Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. *Marine Ecology*, **31**, 21–50.

Cairns, S.D. (2007). Deep-water corals: an overview with special reference to diversity and distribution of deep water Scleractinian corals. *Bulletin of Marine Science*, **81**, 311–322.

Carey, F. (2016). Monitoring cold-water coral reefs, with special reference to anthropogenic impacts, on Giant Mounds, Porcupine Bank, west coast of Ireland. B.Sc. Thesis, National University of Ireland, Galway 51 pp.

Carrassón, M. & Matallanas, J. (2002). Feeding strategies of *Polyacanthonotus rissoanus* (Pisces: Notacanthidae) in the deep western Mediterranean. *Journal of the Marine Biological Association of the United Kingdom*, **82**, 665–671.

CoralFISH (2013). Assessment of the interaction between corals, fish and fisheries, in order to develop monitoring and predictive modelling tools for ecosystem based management in the deep waters of Europe and beyond, EU FP7 Large-scale integrating project no. 213144 Final Periodic Report.

Costello, M.J., McCrea, M., Freiwald, A., Lundalv, T., Jonsson, L., Bett, B.J., van Weering, T.C.E., de Haas, H., Roberts, J.M. & Allen, D. (2005). Role of cold-water *Lophelia pertusa* coral reefs as fish habitat in the NE Atlantic. In: Freiwald, A., Roberts, M. (Eds.), Cold Water Corals and Ecosystems. Springer Verlag, 771–805.

Council Directive (1985). Council Directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri =CELEX:31985L0337&from=ENAccessed October 2020.

Council Directive (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. http://eur-lex.europa.eu/legal-content/EN/TXT/ PDF/?uri=CELEX:31992L0043&from=EN Accessed October 2020.

Council Directive (2001) Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment.http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32001L0042&from=EN Accessed October 2020.

Council Directive (2008) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmentalpolicy.http://eur-lex.europa.eu/ legal-content/EN/TXT/PDF/?uri=CELEX:32008 L0056&from=EN Accessed October 2020.

Council Directive (2009). Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wildbirds.http://eur-lex.europa.eu/legal-content /EN/TXT/PDF/?uri=CELEX:32009L0147&from =EN Accessed October 2020.

Council Directive (2014) Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritimespatialplanning.http://eur-lex.europa .eu/legal-content/EN/TXT/PDF/?uri=CELEX:32 014L0089&from=EN Accessed October 2020.

Dahl, M.P., Pereyra, R.T., Lundalv, T. & Andre, C. (2012). Fine-scale spatial genetic structure and clonal distribution of the cold-water coral *Lophelia pertusa*. *Coral Reefs,* **31**, 1135–1148.

Davies, A.J., Roberts, J.M. & Hall-Spencer, J. (2007). Preserving deep-sea natural heritage: emerging issues in offshore conservation and management. *Biological Conservation*, **138**, 299–312.

Davies, A.J., Wisshak, M., Orr, J.C. & Roberts J.M. (2008). Predicting suitable habitat for the cold-water coral *Lophelia pertusa* (Scleractinia). *Deep-Sea Research*, **55**, 1048–1062.

Davies, J.S., Howell, K.L., Stewart, H.A., Guinan, J. & Golding, N. (2014). Defining biological assemblages (biotopes) of conservation interest in the submarine canyons of the South West Approaches (offshore United Kingdom) for use in marine habitat mapping. *Deep Sea Research Part II: Topical Studies in Oceanography*, **104**, 208-229.

Davies, J.S., Stewart, H.A., Narayanaswamy, B.E., Jacobs, C., Spicer, J., Golding, N. & Howell, K.L. (2015). Benthic assemblages of the Anton Dohrn Seamount (NE Atlantic): defining deep-sea biotopes to support habitat mapping and management efforts with a focus on vulnerable marine ecosystems. *PloS one*, **10**(5), e0124815.De Mol, B., Van Rensbergen, P., Pillen, S., Van Herreweghe, K., Van Rooij, D., McDonnell, A., Huvenne, V., Ivanov, M., Swennen, R. & Henriet, J.P. (2002). Large deep-water coral banks in the Porcupine Basin, southwest of Ireland. *Marine Geology*, **188**, 193–231.

DECLG (2013). Guidelines for Planning Authorities and An Board Pleanala on carrying out Environmental Impact Assessment. http://www.housing.gov.ie/sites/default/files/migrated-files/en/Publications/Developmentand Housing/Planning/FileDownLoad,32720,en.pdf Accessed October 2020.

Dorschel, B., Hebbeln, D., Rüggeberg, A., Dullo, W.C. & Freiwald, A. (2005). Growth and erosion of a cold-water coral covered carbonate mound in the Northeast Atlantic during the Late Pleistocene and Holocene. *Earth and Planetary Science Letters*, **233**, 33–44.

Dorschel, B., Wheeler, A.J., Monteys, X. & Verbruggen, K. (2010). Atlas of the deep-water seabed: Ireland. Springer, Netherlands, 164pp.

Dransfeld, L., Gerritsen, H.D., Hareide, N.R. & Lorance, P. (2013). Assessing the risk of vulnerable species exposure to deepwater trawl fisheries: the case of Orange Roughy *Hoplostethus atlanticus* to the west of Ireland and Britain. *Aquatic Living Resources*, **26**, 307–318.

Duineveld, G.C.A., Lavaleye, M.S.S. & Berghuis, E.M. (2004). Particle flux and food supply to a seamount cold-water coral community (Galicia Bank, NW Spain). *Marine Ecology-Progress Series*, **277**, 13–23.

Duineveld, G.C.A., Lavaleye, M.S.S., Bergman, M.J.N., de Steiger, H. & Milenis, F. (2007). Trophic structure of a cold-water coral mound community (Rockall Bank, NE Atlantic) in relation to the near-bottom particle supply and current regime. *Bulletin of Marine Science*, **81**, 449–467.

Dullo, W.C., Flögel, S. & Rüggeberg, A. (2008). Cold-water coral growth in relation to the hydrography of the Celtic and Nordic European continental margin: *Marine Ecology Progress Series*, **371**, 165–176.

Duncan, P.M. (1878). On the rapidity of growth and variability of some *Madreporaria* on an Atlantic Cable, with remarks upon the rate of accumulation of foraminiferal deposits. *Proceedings of the Royal Society of London*, **26**, 133–137.

Duran Munoz, P., Murillo, F.J., Sayago-Gil, M., Serrano, A., Laporta, M., Otero, I. & Gomez, C. (2011). Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic ecosystem, north-east Atlantic. *Journal of the Marine Biological Association of the United Kingdom*, **91**, 939–952.

European Commission (2013). Interpretation Manual of European Union Habitats. Eur 28. April 2013. European Commission DG Environment. Nature Env B.3. http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf.Accessed October 2020.

Edinger, E.N., Wareham, V.E. & Haedrich, R.L. (2007). Patterns of groundfish diversity and abundance in relation to deep-sea coral distributions in Newfoundland and Labrador waters. *Bulletin of Marine Science*, **81**, 101–122.

Elliott, M., Borja, A., McQuatters-Gollop, A., Mazik, K., Birchenough, S., Andersen, J.H., Painting, S. & Peck, M. (2015). Force majeure: Will climate change affect our ability to attain Good Environmental Status for marine biodiversity? *Marine Pollution Bulletin*, **95**, 7–27.

Fabri, M.C., Pedel, L., Beuck, L., Galgani, F., Hebbeln, D. & Freiwald, A. (2014). Megafauna of vulnerable marine ecosystems in French Mediterranean submarine canyons: Spatial distribution and anthropogenic impacts. *Deep-Sea Research II*, **104**, 184–207.

Fallon, S.J., Thresher, R.E. & Adkins, J. (2013). Age and growth of the cold-water scleractinian *Solenosmilia variabilis* and its reef on SW Pacific seamounts. *Coral Reefs*, **33**, 31–38.

Foley, N.S., van Rensburg, T.M. & Armstrong, C.W. (2011). The rise and fall of the Irish Orange Roughy fishery: An economic analysis. *Marine Policy*, **35**, 756–763.

Frederiksen, R., Jensen, A. & Westerberg, H. (1992). The distribution of the scleractinian coral *Lophelia* pertusa around the Faroe Islands and the relation to internal tidal mixing. *Sarsia*, **77**, 157–171.

Freiwald, A., Fosså, J.H., Grehan, A., Koslow, T. & Roberts, J.M. (2004). Cold-water coral reefs: UNEP-WCMC, Cambridge, UK, v. 84.

Freiwald, A., Wilson, J.B. & Henrich, R. (1999). Grounding Pleistocene icebergs shape recent deep-water coral reefs. *Sedimentary Geology*, **125**, 1–8.

Gass, S.E. & Roberts, J.M. (2006). The occurrence of the cold-water coral *Lophelia pertusa* (Scleractinia) on oil and gas platforms in the North Sea: Colony growth, recruitment and environmental controls on distribution. *Marine Pollution Bulletin*, **52**(5), 549-559.

Genin, A., Dayton, P.K., Lonsdale, P.F. & Speiss, F.N. (1986). Corals on seamount peaks provide evidence of current acceleration over deep-sea topography. *Nature*, **322**, 59–61.

Goldberg, W.M. (1991). Chemistry and structure of skeletal growth rings in the black coral *Antipathes fiordensis* (Cnidaria, Antipatharia): *Hydrobiologia*, **216**, 403–409.

Grehan, A., Unnithan, V., Wheeler, A., Monteys, X., Beck, T., Wilson, M., Guinan, J., Foubert, A. & Klages, M.,J.,T. (2004). Evidence of major fisheries impact on cold-water corals in the deep waters off the Porcupine Bank, west coast of Ireland: are interim management measures required? *ICES Annual Science Meeting* Vigo,1-9.

Grehan, A.J., Unnithan, V., Roy, K.O. & Opderbecke, J. (2005). Fishing impacts on Irish deepwater coral reefs: Making a case for coral conservation, in *Proceedings Benthic habitats and the effects of fishing*. American Fisheries Society Symposium, 41, Tampa, Bethesda, Maryland, 819-832.

Gruber, N., Bakker, D.C.E., DeVries, T. Gregor, T., Hauck, J., Landschützer, P., McKinley, A.A. & Müller, J.D. (2023). Trends and variability in the ocean carbon sink. *Nature Reviews Earth and Environment*, **4**, 119–134.

Guinan, J., Brown, C., Dolan, M.F.J. & Grehan, A.J. (2009). Ecological niche modelling of the distribution of cold-water coral habitat using underwater remote sensing data. *Ecological Informatics*, **4**, 83–92.

Guinan, J. & Leahy, Y. (2009). Habitat Mapping of Geogenic Reef Offshore Ireland. An Unpublished report to the National Parks and Wildlife Service.

Guinotte, J.M., Orr, J., Cairns, S., Freiwald, A., Morgan, L. & George, R. (2006). Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Frontiers in Ecology and the Environment*, **4**(3), 141-146.

Hall-Spencer, J., Allain, V. & Fossa, J.H. (2002). Trawling damage to Northeast Atlantic ancient coral reefs. *Proceedings of the Royal Society B-Biological Sciences*, **269** (1490), 507-511.

Hall-Spencer, J.M., Rogers, A., Davies, J. & Foggo, A. (2007). Deep-sea coral distributions on seamounts, oceanic island and continental slope in the NE Atlantic. *Bulletin of Marine Science*, **81** (Supplement 1), 135–146.

Harris, P.T., Macmillan-Lawler, M., Rupp, J. & Baker, E.K. (2014). Geomorphology of the oceans: *Marine Geology*, **352**, 4–24.

Harvey, J. (1982). θ-S relationships and water masses in the eastern North Atlantic. *Deep Sea Research Part A. Oceanographic Research Papers*, **29**, 1021–1033.

Hastings, M. (2008). Effects of sound on shallow coral reefs and predicted effects for the Gigas seismic survey in and around north Scott Reef lagoon. Technical report for Woodside Energy (Ireland) Pty Ltd Sinclair Knight Merz Pty Limited WV03377.221.

Hennige, S.J., Wicks, L.C., Kamenos, N.A., Bakker, D.C.E., Findlay, H.S., Dumousseaud, C. & Roberts, J.M. (2014). Short-term metabolic and growth responses of the cold-water coral *Lophelia pertusa* to ocean acidification: *Deep Sea Research Part II*, **99**, 27–35.

Hennige, S.J., Wicks, L.C., Kamenos, N.A., Perna, G., Findlay, H.S. & Roberts, J.M. (2015). Hidden impacts of ocean acidification to live and dead coral framework. *Proceedings of the Royal Society of Biological Sciences*, **282**, 1183.

Henry, L.A. & Roberts, J.M. (2007). Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep Sea Research I*, **54**, 654–672.

Henry, L.A. & Roberts, J.M. (2013). Recommendations for best practice in deep-sea habitat classification: Bullimore *et al.* as a case study. *ICES Journal of Marine Science*, **71**, 895 – 898.

Hernández-Kantún, J.J., Sherwood, A.R., Riosmena-Rodriguez, R., Huisman, J.M. & de Clerck, O. (2012). Branched Halymenia species (*Halymeniaceae, Rhodophyta*) in the Indo-Pacific region, including descriptions of *Halymenia hawaiiana sp. nov.* and *H. tondoana sp. nov. European Journal of Phycology*, **47**, 421–432.

Hilário, A., Metaxas, A., Gaudron, S.M., Howell, K.L., Mercier, A., Mestre, N.l.C., Ross, R.E., Thurnherr, A.M. & Young, C. (2015). Estimating dispersal distance in the deep sea: challenges and applications to marine reserves. *Frontiers in Marine Science*, **2**, 6.

Holliday, P. & Cunningham, S. (2013). The Extended Ellett Line: Discoveries from 65 Years of Marine Observations West of the UK. *Oceanography*, **26**, 156–163.

Hovland, M. (2008). Deep Water Coral Reefs: Unique Biodiversity Hot-spots. Chichester: Springer-Praxis.

Hovland, M., Mortensen, P.B., Brattegard, T., Strass, P. & Rokoengen, K. (1998). Ahermatypic coral banks off mid-Norway: Evidence for a link with seepage of light hydrocarbons. *Palaios*, **13**, 189–200.

Husebø, A., Nottestad, L., Fóssa, J.H., Furevik, D.M. & Jorgensen, S.B. (2002). Distribution and abundance of fish in deep-sea coral habitats. *Hydrobiologia,* **471**, 91–99.

Huvenne, V.A.I., Beyer, A., de Haas, H., Dekindt, K., Henriet, J.P., Kozachenko, M., Olu-Le Roy, K., Wheeler, A., TOBI/Pelagia 197 & CARACOLE Cruise Participants (2005). The seabed appearance of different coral bank provinces in the Porcupine Seabight, NE Atlantic: results from side-scan sonar and ROV seabed mapping. In: Freiwald A., Roberts J.M. (eds.) Cold-Water Corals and Ecosystems. Erlangen Earth Conference Series. Springer, Berlin, Heidelberg.

Huvenne, V.A.I., Bailey, W.R., Shannon, P.M., Naeth, J., di Primio, R., Henriet, J.P., Horsfield, B., de Haas, H., Wheeler, A. & Roy, K.O.L. (2007). The Magellan mound province in the Porcupine Basin. *International Journal of Earth Sciences,* **96**, 85–101.

Huvenne, V.A.I., Duineveld, G.C.A. & Cruise 64PE313 Participants (2009). CoralFish-Hermione Cruise Report, Galway-Lisbon, 16 Oct - 5 Nov 2009; Belgica Mound Province (Coralfish & Hermione), Whittard Canyon (Hermione) and Galicia Bank Area (Biofun). Royal Netherlands Institute for Sea Research, Texel, The Netherlands. https://epic.awi.de /29999/1/CoralFISH_NIOZ-64PE313_Cruise_ Report.pdf Accessed October 2020.

Huvenne, V.A.I., Tyler, P.A., Masson, D.G., Fisher, E.H., Hauton, C., Hühnerbach, V., Le Bas, T.P. & Wolff, G.A. (2011). A Picture on the Wall: Innovative Mapping Reveals Cold-Water Coral Refuge in Submarine Canyon. *PLoS ONE,* **6**, 12.

ICES (2009). Report of the ICES-NAFO Working Group on Deep-Water Ecology (WGDEC), 9 - 13 February 2009. *International Council for the Exploration of the Seas* CM 2009/ACOM, **23**,94.

IOOA (2015). Cold-water corals and offshore hydrocarbon exploration operations on the Irish Atlantic Margin; A knowledge Exchange Workshop. *Irish Offshore Operators Association,* https://iooa.files.wordpress.com/2015/06/iooa_cold-water-corals-workshop-report_december-2014.pdf Accessed October 2020.

Jensen, A. & Frederiksen, R. (1992). The fauna associated with the bank-forming deepwater coral *Lophelia pertusa* (Scleractinaria) on the Faroe shelf. *Sarsia,* **77**, 53–69.

JNCC (2015) The Marine Habitat Classification for Britain and Ireland Version 15.03. https://mhc.jncc.gov.uk/

JNCC (2023) Marine Habitat Classification for Britain and Ireland (22.04): Overview of changes since MHCBI 15.03.

https://data.jncc.gov.uk/data/f9a6a2be-e6be-4f7f-8605-28c1b4062658/2204-mhcbi-overview-of-changes-v2023-01.pdf

Johnson, M.P., White, M., Wilson, A., Würzberg, L., Schwabe, E., Folch, H. & Allcock, A.L. (2013). Vertical Wall Dominated by *Acesta excavata* and *Neopycnodonte zibrowii*, Part of an Undersampled Group of Deep-Sea Habitats. PLoS ONE **8(11)**, e79917. https://doi.org/10. 1371/journal. pone.0079917

Johnston, C.M., Turnbull, C.G. & Tasker, M.L. (2002). Natura 2000 in UK Offshore waters: advice to support the implementation of the EC Habitats and Birds Directives in UK offshore waters. *JNCC Report,* **325**.

Jonsson, L.G., Nilsson, P.G., Floruta, F. & Lundalv, T. (2004). Distributional patterns of macro and megafauna associated with a reef of the cold-water coral *Lophelia pertusa* on the Swedish west coast. *Marine Ecology Progress Series,* **284**, 163–171.

Kano, A., Ferdelman, T.G., Williams, T., Henriet, J.P., Ishikawa, T., Kawagoe, N., Takahashima, C., Kakizaki, Y., Abe, K., Sakai, S., Browning, E.L., Li, X. & Integrated Ocean Drilling Program Expedition 307 Scientists (2007). Age constraints on the origin and growth history of a deep water coral mound in the northeast Atlantic drilled during Integrated Ocean Drilling Program Expedition 307. *Geology,* **35**, 1051–1054.

Kenyon, N.H., Akmetzhanov, A.M., Wheeler, A.J., van Weering, T.C.E., de Haas, H. & Ivanov, M.K. (2003). Giant carbonate mud mounds in the southern Rockall Trough. *Marine Geology,* **195**, 5–30.

Lampitt, R.S., Bett, B.J., Kiriakoulakis, K., Popova, E.E., Ragueneau, O., Vangriesheim, A. & Wolff, G.A. (2001). Material supply to the abyssal seafloor in the Northeast Atlantic. *Progress in Oceanography,* **50**, 27–63.

Lankhorst, M. & Zenk, W. (2006). Lagrangian observations of the middepth and deep velocity fields of the northeastern Atlantic Ocean. *Journal of Physical Oceanography,* **36**, 43–63.

Larsson, A.I., Jarnegren, J., Stromberg, S.M., Dahl, M.P., Lundalv, T. & Brooke, S. (2014). Embryogenesis and larval biology of the cold-water coral *Lophelia pertusa*. *PLoS ONE,* **9**(7), e102222.

Le Goff-Vitry, M.C., Pybus, O.G. & Rogers, A.D. (2004). Genetic structure of the deep-sea coral *Lophelia pertusa* in the northeast Atlantic revealed by microsatellites and internal transcribed spacer sequences. *Molecular Ecology,* **13**, 537–549.

Le Guilloux, E., Hall-Spencer, J.M., Söffker, M.K. & Olu, K. (2010). Association between the squat lobster *Gastroptychus formosus* and cold-water corals in the North Atlantic. *Journal of the Marine Biological Association of the United Kingdom*, **90**, 1363–1369.

Linley, T.D., Lavaleye, M., Maiorano, P., Bergman, M., Capezzuto, F., Cousins, N.J., D'Onghia, G., Duineveld, G., Shields, M.A., Sion, L., Tursi, A. & Priede, I.G. (2015). Effects of cold-water corals on fish diversity and density (European continental margin: Arctic, NE Atlantic and Mediterranean Sea): Data from three baited lander systems. *Deep-Sea Research Part II.*

Martín, J., Puig, P., Palanques, A. & Ribó, M. (2014). Trawling-induced daily sediment re-suspension in the flank of a Mediterranean submarine canyon. *Deep Sea Res Part II,* **104**, 174–183.

McGrath, T., Kivimäe, C., Tanhua, T., Cave, R.R. & McGovern, E. (2012). Inorganic carbon and pH levels in the Rockall Trough 1991-2010. *Deep-Sea Research Part I,* **68**, 79–91.

Mercier, A. & Hamel, J.F. (2011). Contrasting reproductive strategies in three deep-sea octocorals from eastern Canada. *Primnoa resedaeformis*, *Keratoisis ornata*, and *Anthomastus grandiflorus*. *Coral Reefs,* **30**, 337-350.

Mienis, F., van Weering, T., de Haas, H., de Stigter, H., Huvenne, V. & Wheeler, A. (2006). Carbonate mound development at the SW Rockall Trough margin based on high resolution TOBI and seismic recording. *Marine Geology*, **233**, 1–19.

Mohn, C., Rengstorf, A., White, M., Duineveld, G., Mienis, F., Soetaert, K. & Grehan, A. (2014). Linking benthic hydrodynamics and cold-water coral occurrences: A high-resolution model study at three cold-water coral provinces in the NE Atlantic. *Progress in Oceanography*, **122**, 92–104.

Morato, T., González-Irusta, J.M., Dominguez-Carrió, C., Wei, C.L., Davies, A., Sweetman, A.K., Taranto, G.H., Beazley, L., García-Alegre, A., Grehan, A. & Laffargue, P. (2020). Climate-induced changes in the suitable habitat of cold-water corals and commercially important deep-sea fishes in the North Atlantic. *Global Change Biology*, **26**(4), 2181-2202.

Morris, K.J., Tyler, R.A., Masson, D.G. Huvenne, V.I.A. & Rogers, A. (2013). Distribution of cold water corals in the Whittard Canyon NE Atlantic. *Deep Sea Research II*, **92**, 136–144.

Morrison, C.L., Ross, S.W., Nizinski, M.S., Brooke, S., Järnegren, J., Waller, R.G., Johnson, R.L. & King, T.L. (2011). Genetic discontinuity among regional populations of *Lophelia pertusa* in the North Atlantic Ocean. *Conservation Genetics,* **12**, 713–729.

Mortensen, P.B., Hovland, M., Brattegard, T. & Farestveit, R. (1995). Deep water bioherms of the scleractinian coral *Lophelia pertusa* (L.) at

64ºN on the Norwegian shelf: structure and associated megafauna. *Sarsia,* **80**, 145–158.

Mortensen, P.B., Hovland, M.T., Fosså, J.H. & Furevik, D.M. (2001). Distribution, abundance and size of *Lophelia pertusa* coral reefs in mid-Norway in relation to seabed characteristics. *Journal of the Marine Biological Association of the United Kingdom,* **81**, 581–597.

NPWS (2013a). The Status of EU Protected Habitats and Species in Ireland. Habitat Assessments Volume 1. Version 1.1. Unpublished Report, National Parks & Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland. https://www.npws.ie/sites/default/files /publications/pdf/Art17-Vol1-web.pdf_Accessed May 2024.

NPWS (2013b). The Status of Protected EU Habitats and Species in Ireland. Habitats Volume 2. Unpublished Report, National Parks and Wildlife Service. 843 pp. http://www.npws.ie/ sites/default/files/publications/pdf/Article_17_Print_Vol_2_report_habitats_v1_1_0.pdf Accessed May 2024.

NPWS (2013c). The Status of EU Protected Habitats and Species in Ireland. Habitat Assessments Volume 1. Version 1.1. Unpublished Report, National Parks & Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland. https://www.npws.ie/sites/default/files /publications/pdf/Article_17_Print_Vol_3_report _species_v1_1_0.pdf Accessed May 2024.

NPWS (2014a). Site Synopsis. Site Name: North-west Porcupine Bank SAC. Site Code 002330. Rev13. Ver. 09.01.2014. https://www.npws.ie/ sites/default/files/protected-sites/synopsis/ SY002330.pdf Accessed May 2024.

NPWS (2014b). Site Synopsis. Site Name: Hovland Mound Province SAC. Site Code 002328. Rev13. Ver. 06.01.2014. https://www.npws.ie /sites/default/files/protected-sites/synopsis/ SY002328.pdf Accessed May 2024.

NPWS (2014c). Site Synopsis. Site Name: South-east Rockall Bank SAC. Site Code 003002. Rev13. Ver. 10.022014. https://www.npws.ie/sites /default/files/protected-sites/synopsis/SY003002.pdf Accessed May 2024.

NPWS (2019a). The Status of EU Protected Habitats and Species in Ireland. Volume 2: Habitat Assessments. Unpublished NPWS report. National Parks and Wildlife Service, Department of Housing, Local Government and Heritage, Dublin, Ireland.

NPWS (2019b). The Status of EU Protected Habitats and Species in Ireland. Volume 1: Summary Overview. Unpublished NPWS report. National Parks and Wildlife Service, Department of Housing, Local Government and Heritage, Dublin, Ireland.

NPWS (2023a). Site Synopsis. Site Name: Porcupine Shelf SAC. Site Code: 002267. Rev22. Ver. 07.03.2023. https://www.npws.ie/sites/default/files/protected-sites/synopsis/SY002267.pdf Accessed May 2024.

NPWS (2023b). Site Synopsis. Site Name: Southern Canyons SAC. Site Code: 002278. Rev22. Ver. 07.03.2023. https://www.npws.ie/sites/default/files/protected-sites/synopsis/SY002278.pdf Accessed May 2024.

NPWS (2023c). SAC and SPA Datasheets Downloads (online) Available: https://www.npws.ie/maps-and-data/designated-site-data/sac-and-spa-datasheets-downloads Accessed April 2024.

NPWS (2024a). Site Synopsis. Site Name: Belgica Mound Province SAC. Site Code 002327. Rev24. Ver. 20.03.2024. https://www.npws.ie/sites/default/files/protected-sites/synopsis/SY002327.pdf.pdf Accessed May 2024.

NPWS (2024b). Site Synopsis. Site Name: South-west Porcupine Bank SAC. Site Code 002329. Rev24. Ver. 20.03.2024. https://www.npws.ie/ sites/default/files/protected-sites/synopsis/ SY002329.pdf Accessed May 2024.

NPWS (2024c). Site Synopsis. Site Name: Porcupine Bank Canyon SAC. Site Code 003001. Rev24. Ver. 20.03.2024. https://www.npws.ie/sites/default /files/protected-sites/synopsis/SY003001.pdf Accessed May 2024.

Norton, C., Barnes, J., O'Broin, D., Flannery, W., Adamson, C. & Berne, S. (2016). Towards an Integrated Policy Framework for Maritime Spatial Planning in Ireland: Recommendations for Preparing Maritime Spatial Plans in Ireland https://www.epa.ie/publications/research/water/ research-report-174.php.Accessed May 2024.

Orejas, C., Gori, A. & Gili, J.M. (2008). Growth rates of live *Lophelia pertusa* and *Madrepora oculata* from the Mediterranean Sea maintained in aquaria. *Coral Reefs,* **27**, 255.

Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., Gnanadesikan, A., Gruber, N., Ishida, A., Joos, F., Key, R.M., Lindsay, K., Maier-Reimer, E., Matear, R., Monfray, P., Mouchet, A., Najjar, R.G., Plattner, G.K., Rodgers, K.B., Sabine, C.L., Sarmiento, J.L., Schlitzer, R., Slater, R.D., Totterdell, I.J., Weirig, M.F., Yamanaka, Y. & Yool, A. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, **437**, 681–686.

OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) (2009). Background Document for *Lophelia* *pertusa* reefs. Biodiversity Series. https://pearl.plymouth.ac.uk/bitstream/handle/10026.1/1369/Hall-Spencer%20OSPAR%20lophelia%202009.pdf?sequence=2&isAllowed=y Accessed October 2020.

OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) (2010). Background Document for Carbonate Mounds. Biodiversity Series. http://qsr2010.ospar.org/media/assessments/Species/P00489_carbonate_mounds.pdf Accessed October 2020.

O'Sullivan D., Leahy Y., Healy L. & the Shipboard Scientific Party (2018). EMFF Off-shore Reef Survey, Sensitive Ecosystem Assessment and ROV Exploration of Reef - SeaRover 2018 Cruise Report. Cruise Report prepared by INFOMAR, the Marine Institute, Galway, Ireland and the National Parks and Wildlife Service for the Department of Agriculture, Food and the Marine, the European Maritime and Fisheries Fund and the Department of Culture, Heritage and the Gaeltacht.

O'Sullivan D., Leahy Y., Healy L. & the Shipboard Scientific Party (2019). EMFF Off-shore Reef Survey, Sensitive Ecosystem Assessment and ROV Exploration of Reef - SeaRover 2019 Cruise Report. Cruise Report prepared by INFOMAR, the Marine Institute, Galway, Ireland and the National Parks and Wildlife Service for the Department of Agriculture, Food and the Marine, the European Maritime and Fisheries Fund and the Department of Culture, Heritage and the Gaeltacht.

Palanques, A., Martín, J., Puig, P., Guillén, J., Company, J.B. & Sardà, F. (2006). Evidence of sediment gravity flows induced by trawling in the Palamós (Fonera) submarine canyon (northwestern Mediterranean). *Deep-Sea Research I*, **53**, 201–214.

Parks, J.E., Pomeroy, R.S. & Watson, L.M. (2004). How is your MPA doing?: a guidebook of natural and social indicators for evaluating marine protected areas management effectiveness. *IUCN*, 215 p., https://doi.org/10.2305/IUCN.CH.2004.PAPS.1.en

Pham, C.K., Diogo, H., Menezes, G., Porteiro, F., Braga-Henriques, A., Vandeperre, F. & Morato, T. (2014a). Deep-water longline fishing has reduced impact on Vulnerable Marine Ecosystems. *Scientific Reports,* **4**(1), 1-6.

Pham, C.K., Ramirez-Llodra, E., Alt, C.H., Amaro, T., Bergmann, M., Canals, M., Company, J.B., Davies, J., Duineveld, G., Galgani, F., Howell, K. L., Huvenne, V.A., Isidro, E., Jones, D.O., Lastras, G., Morato, T., Gomes-Pereira, J.N., Purser, A., Stewart, H., Tojeira, I., Tubau, X., Van Rooij, D. & Tyler, P.A. (2014b). Marine litter distribution and density in European seas, from the shelves to deep basins. *PLoS ONE* **9**(4), e95839.

Picton, B.E., Morrow, C.C., Scally, L., Pfeiffer, N. & McGrath, F. (2021). Sensitive Ecosystem Assessment and ROV Exploration of Reef (SeaRover) Synthesis Report. EMFF 2014-2020 Marine Institute Report Series. Report prepared by MERC Consultants Ltd. on behalf of the Marine Institute, Galway, 161 pp.

Pollard, R.T., Griffiths, M.J., Cunningham, S.A., Read, J.F., Perez, F.F. & Rios, A.F. (1996). Vivaldi 1991-A study of the formation, circulation and ventilation of Eastern North Atlantic Central Water. *Progress in Oceanography*, **37**, 167–192.

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D.A., Bartol, S., Carlson, T.J., Coombs, S., Ellison, W.T., Gentry, R.L., Halvorsen, M.B., Løkkeborg, S., Rogers, P.H., Southall, B.L., Zeddies, G.D. & Tavolga, W.N. (2014). Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. ASA S3/SC1.4 TR-2014. Springer and ASA Press, Cham, Switzerland. doi: 10.1007/978-3-319-06659-2.

PROTECT (2009). Marine Protected Areas as a Tool for Ecosystem Conservation and Fisheries Management, EU FP6 Project SSP8-CT-2004-513670 Synthesis Report, 106 pp.

Prouty, N., Roark, E., Buster, N. & Ross, S. (2011). Growth rate and age distribution of deep-sea black corals in the Gulf of Mexico. *Marine Ecology Progress Series,* **423**, 101–115.

Prouty, N.G., Fisher, C.R., Demopoulos, A.W.J. & Druffel, E.R.M. (2016). Growth rates and ages of deep-sea corals impacted by the Deepwater Horizon oil spill. *Deep Sea Research II,* **129**, 196–212.

Puig, P., Canals, M., Company, J.B., Martín, J., Amblas, D., Lastras, G., Palanques, A. & Calafat, A.M. (2012). Ploughing the deep sea floor. *Nature,* **489**, 286-289.

Pusceddu, A., Bianchelli, S., Martín, J., Puig, P., Palanques, A., Masqué, P. & Danovaro, R. (2014). Chronic and intensive bottom trawling impairs deep-sea biodiversity and ecosystem functioning. *Proceedings of the National Academy of Sciences,* **111**(24), 8861-8866.

Ramirez-Llodra, E., Brandt, A., Danovaro, R., De Mol, B., Escobar, E., German, C.R., Levin, L.A., Martinez Arbizu, P., Menot, L., Buhl-Mortensen, P. & Narayanaswamy, B.E. (2010). Deep, diverse and definitely different: unique attributes of the world's largest ecosystem. *Biogeosciences*, **7**(9), 2851-2899.

Reed, J.K, Messing, C., Walker, B., Brooke, S., Correa, T., Brouwer, M. & Udouj, T. (2013). Habitat characterization, distribution, and areal extent of deep-sea coral ecosystem habitat off

Florida, southeastern United States. C*aribbean Journal of Science,* **47**, 13–30.

Rengstorf, A.M. (2013). High-resolution habitat suitability modelling of vulnerable marine ecosystems in the deep sea. Ph.D. Thesis, National University of Ireland, Galway. http://hdl.handle.net/10379/3694 Accessed October 2020.

Rengstorf, A.M., Yesson, C., Brown, C. & Grehan, A. J. (2013). High-resolution habitat suitability modelling can improve conservation of vulnerable marine ecosystems in the deep sea. *Journal of Biogeography,* **40**, 1702–1714.

Rengstorf, A.M., Grehan, A.J., Yesson, C. & Brown, C. (2012). Towards High-Resolution Habitat Suitability Modeling of Vulnerable Marine Ecosystems in the Deep-Sea: Resolving Terrain Attribute Dependencies. *Marine Geodesy* **35**, 343–361.

Ridge, S.M. & McKinley, G.A. (2021). Ocean carbon uptake under aggressive emission mitigation. *Biogeosciences*, **18**(8), 2711-2725.

Risk, M.J., Heikoop, J.M., Snow, M.G. & Beukens, R. (2002). Lifespans and growth patterns of two deep-sea corals: *Primnoa resedaeformis* and *Desmophyllum cristagalli*. *Hydrobiologia,* **471**, 125–131.

Roark, E.B., Guilderson, T.P., Dunbar, R.B. & Ingram, B.L. (2006). Radiocarbon-based ages and growth rates of Hawaiian deep-sea corals. *Marine Ecology Progress Series,* **327**, 1–14.

Roark, E.B., Guilderson, T.P., Dunbar, R.B., Fallon, S.J. & Mucciarone, D.A. (2009). Extreme longevity in proteinaceous deep-sea corals: *Proceedings of the National Academy of Sciences,* **106**, 5204–5208.

Robert, K., Jones, D.O.B., Tyler, P.A. Van Rooij, D. & Huvenne, V.A.I. (2015). Finding the hotspots within a biodiversity hotspot: fine-scale biological predictions within a submarine canyon using high-resolution acoustic mapping techniques. *Marine Ecology*, **36**, 1256–1276.

Roberts, J.M. (2002). The occurrence of the coral *Lophelia pertusa* and other conspicuous epifauna around an oil platform in the North Sea. *Underwater Technology*, **25**, 83–91.

Roberts, J.M., Wheeler, A.J. & Freiwald, A. (2006). Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science*, **213**, 543–547.

Roberts, J.M., Wheeler, A., Freiwald, A. & Cairns, S. (2009). Cold-water corals. The Biology and Geology of Deep-Sea Coral Habitats. Springer. Cambridge University Press.

Rogers, A.D. (1999). The biology of *Lophelia pertusa* (Linnaeus 1758) and other deepwater reef-forming corals and impacts from human activities. *International Review of Hydrobiology*, **84**, 315–406.

Rogers, A.D., Baco, A., Griffiths, H., Hart, T. & Hall-Spencer, J.M. (2007). Corals on Seamounts. In Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. Santos, R.S. (Eds.) Seamounts: Ecology, Fisheries and Conservation. Fish and Aquatic Resources Series, Blackwell, Oxford, UK. Pp 141 – 169.

Rogers, A.D., Clark, M.R., Hall-Spencer, J.M. & Gjerde, K.M. (2008). The Science behind the Guidelines: A Scientific Guide to the FAO Draft International Guidelines (December 2007) For the Management of Deep-Sea Fisheries in the High Seas and Examples of How the Guidelines May Be Practically Implemented. IUCN, Switzerland, 2008.

Ross, R., La Bianca, G. & Howell, K. (2018) SEAROVER 2017 Deep Water Reef Habitat & Species Video Analysis Full Report. Unpublished Report to the Marine Institute (Ref: ITT17-050). https://data.marine.ie/data/IrelandsSeabedCatalogue/SeaRover%202017/VideoAnalysisReport/Video_Analysis_Report_SeaRover2017.pdf Accessed May 2024.

Ross, R. (2016). Investigating the role of larval dispersal models in the development of an 'ecologically coherent' network of deep-sea marine protected areas. Ph.D. Thesis, University of Plymouth, UK. http://hdl.handle.net/10026.1/6560 Accessed May 2024.

Ross, L.K., Ross, R.E., Stewart, H.A. & Howell, K.L. (2015). The influence of data resolution on predicted distribution and estimates of extent of current protection of three ‘listed’ deep-sea habitats. *PloS one*, **10**(10), e0140061.

Ross, R.E. & Howell, K.L. (2013). Use of predictive habitat modelling to assess the distribution and extent of the current protection of “listed” deep-sea habitats. Diversity and Distributions *Early View*, **19**, 433–445.

Ross, S.W. & Quattrini, A.M. (2007). The fish fauna associated with deep coral banks off the southeastern United States. *Deep-Sea Research I,* **54**, 975–1007.

Rüggeberg, A., Dullo, C., Dorschel, B. & Hebbeln, D. (2007). Environmental changes and growth history of a cold-water carbonate mound (Propeller Mound, Porcupine Seabight). *International Journal of Earth Sciences,* **96**, 57–72.

Sañé, E., Martín, J., Puig, P. & Palanques, A. (2013). Organic biomarkers in deep-sea regions affected by bottom trawling: Pigments, fatty acids, amino acids and carbohydrates in surface sediments from the La Fonera (Palamós) Canyon, NW Mediterranean Sea. *Biogeosciences*, **10**, 8093–8108.

Saul, R., Barnes, R. & Elliott, M. (2016). Is climate change an unforeseen, irresistible and external factor - A force majeure in marine environmental law? *Marine Pollution Bulletin*, **113**(1-2), 25-35.

Shephard, S. & Rogan, E. (2006). Seasonal distribution of Orange Roughy (*Hoplostethus atlanticus*) on the Porcupine Bank west of Ireland. *Fisheries Research*, **77**(1), 17-23.

Sherwood, O.A. & Edinger, E.N. (2009). Ages and growth rates of some deep-sea gorgonian and antipatharian corals of Newfoundland and Labrador. *Canadian Journal of Fisheries and Aquatic Sciences*, **66**, 142–152.

Soetaert, K., Mohn, C., Rengstorf, A., Grehan, A. & van Oevelen, D. (2016). Ecosystem engineering creates a direct nutritional link between 600-m deep cold-water coral mounds and surface productivity. *Scientific Reports,* **6**(1), 35057.

Söffker, M., Sloman, K.A. & Hall-Spencer, J.M. (2011). In situ observations of fish associated with coral reefs off Ireland. *Deep-Sea Research I,* **58**, 818–825.

Stapleton, F., Murray, J., Grehan, A., Duffy, G. & Williams, M. (2013). A Geological and Geophysical Description of the Arc Mounds, southwest Porcupine Bank. M.Sc. Thesis, National University of Ireland, Galway.

Stone, R. (2006). Coral habitat in the Aleutian Islands of Alaska: depth distribution, fine-scale species associations, and fisheries interactions: *Coral reefs,* **25**, 229–238.

Sumina, P. & Kennedy, R. (1998). Porcupine Seabight. Biological data. In: Kenyon, N.H., Ivanov, M.K. & Akhmetzhanov, A.M., (Eds.) Cold water carbonate mounds and sediment transport on the Northeast Atlantic margin. Intergovernmental Oceanographic Commission Technical Series, **52**, UNESCO.

Sweetman, A.K., Thurber, A.R., Smith, C.R., Levin, L.A., Mora, C., Wei, C.L., Gooday, A.J., Jones, D.O., Rex, M., Yasuhara, M. & Ingels, J., (2017). Major impacts of climate change on deep-sea benthic ecosystems. *Elementa: Science of the Anthropocene*, **5**, 4.

Taylor, M., Gwinnett, C., Robinson, L. & Woodall, L. (2016). Plastic microfibre ingestion by deep-sea organisms. *Scientific Reports,* **6**(1), 33997.

Thiel, H., Pfannkuche, O., Schriever, G., Lochte, K., Gooday, A.J., Hemleben, C., Mantoura, R.F.G., Turley, C.M., Patching, J.W. & Riemann, F. (1989). Phytodetritus on the Deep-Sea Floor in a Central Oceanic Region of the Northeast Atlantic. *Biological Oceanography*, **6**, 203–239.

Thiem, Ø., Ravagnan, E., Fosså, J.H. & Berntsen, J. (2006). Food supply mechanisms for cold-water corals along a continental shelf edge. *Journal of Marine Systems,* **26**, 1481–1495.

Thierens, M., Titschack, J., Dorschel, B., Huvenne, V.A.I., Wheeler, A.J., Stuut, J.B. & O'Donnell, R. (2010). The 2.6 Ma depositional sequence from the Challenger cold-water coral carbonate mound (IODP Exp. 307): Sediment contributors and hydrodynamic palaeo-environments: *Marine Geology*, **271**, 260–277.

Tittensor, D.P., Baco, A.R., Brewin, P.E., Clark, M.R., Consalvey, M., Hall-Spencer, J.M., Rowden, A.A., Schlacher, T., Stocks, K.I. & Rogers, A.D. (2009). Predicting global habitat suitability for stony corals on seamounts. *Journal of Biogeography,* **36**, 1111–1128.

Turley, C.M., Roberts, J.M. & Guinotte, J.M. (2007). Corals in deep-water: will the unseen hand of ocean acidification destroy cold-water ecosystems? *Coral Reefs*, **26**, 445–448.

Tyler, P.A. & Zibrowius, H. (1992). Submersible observations of the invertebrate fauna on the continental-slope southwest of Ireland (NE Atlantic-Ocean). *Oceanologica Acta*, **15**, 211–226.

Ulfsnes, A., Haugland, J.K. & Weiltzien, R. (2015). Monitoring of drilling activities in areas with presence of cold-water corals. A report for Norsk Olje og Gass.

van Weering, T.C.E., de Haas, H., de Stiger, H.C., Lykke-Andersen, H. & Kouvaev, I. (2003). Structure and development of giant carbonate mounds at the SW and SE Rockall Trough margins, NE Atlantic Ocean. *Marine Geology*, **198**, 67–81.

Wagner, D., Luck, D.G. & Toonen, R.J. (2012). The biology and ecology of black corals (Cnidaria: Anthozoa: Hexacorallia: Antipatharia). *Advances in Marine Biology*, **63**, 67–132.

Wagner, D., Waller, R.G. & Toonen, R.J. (2011). Sexual reproduction of Hawaiian black corals, with a review of the reproduction of antipatharians (Cnidaria: Anthozoa: Hexacorallia). *Invertebrate Biology*, **130**, 211–225.

Waller, R.G. & Tyler, P.A. (2005). The reproductive biology of two deep-water, reef-building Scleractinians from the NE Atlantic Ocean. *Coral Reefs*, **24**, 514–522.

Warner, G.F. (2005). The occurrence of black corals in Jamaican reef environments, with special reference to *Stichopathes lutkeni* (Antipatharia:Antipathidae). *Revista de Biología Tropical,* **53**, 61–66.

Watling, L., France, S.C., Pante, E. & Simpson, A. (2011). Biology of deep-water octocorals. *Advances in Marine Biology*, **60**, 41–122.

Wheeler, A.J., Beck, T., Thiede, J., Klages, M., Grehan, A. Monteys, F.X. and Polarstern ARK XIX/3a Shipboard Party (2005). Deep-water coral mounds on the Porcupine Bank, Irish margin: preliminary results from Polarstern ARK-XIX/3a ROV cruise. In Freiwald, A., Roberts, J.M., (Eds.) Cold-water Corals and Ecosystems. Springer, Berlin, 393–402.

Wheeler, A.J., Beyer, A., Freiwald, A., de Haas, H., Huvenne, V.A.I., Kozachenko, M., Olu-Le

Roy, K. & Opderbecke, J. (2007). Morphology and environment of cold-water coral carbonate mounds on the NW European margin. *International Journal of Earth Sciences*, **96**, 37–56.

White, M. (2007). Benthic dynamics at the carbonate mound regions of the Porcupine Sea Bight continental margin. *International Journal of Earth Sciences,* **96**, 1–9.

White, M., Mohn, C., de Stigter, H. & Mottram, G. (2005). Deep-water coral development as a function of hydrodynamics and surface productivity around the submarine banks of the Rockall Trough, NE Atlantic. In: Freiwald, A., Roberts, J.M. (Eds.), Cold-Water Corals and Ecosystems. Springer, Berlin/Heidelberg, 503–514.

Wienberg, C., Beuck, L., Heidkamp, S., Hebbeln, D., Freiwald, A., Pfannkuche, O. & Monteys, X. (2008). Franken Mound: facies and biocoenoses on a newly-discovered ‘carbonate mound’ on the western Rockall Bank, NE Atlantic. *Facies,* **54**, 1–24.

Wilson, A.M., Raine, R., Mohn, C. & White, M. (2015). Nepheloid layer distribution in the Whittard Canyon, NE Atlantic Margin. *Marine Geology,* **367**, 130–142.

Wilson, J.B. (1979). ‘Patch’ development of the deep-water coral *Lophelia pertusa* (L.) on Rockall Bank. *Journal of the Marine Biological Association of the United Kingdom,* **59**, 165–177.

Wilson, J. & Vina Herbon, C. (1998). Macrofaunas and Biogenic carbonates from the north slope of Porcupine Bank, south east slope of Rockall Bank and west of Faeroe Bank Channel. In: Cold water carbonate mounds and sediment transport on the Northeast Atlantic margin. In Kenyon, N.H., Ivanov, M.K., Akhmetzhanov, A.M (Eds.) Intergovernmental Oceanographic Commission Technical Series 52. UNESCO 1998.

Wilson, M.F.J., O'Connell, B., Brown, C., Guinan, J.C. & Grehan, A.J. (2007). Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the continental slope. *Marine Geodesy*, **30**, 3–35.

Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E. & Thompson, R.C. (2014). The deep sea is a major sink for microplastic debris. *Royal Society open science*, **1**(4), 140317.

Yesson, C., Taylor, M.L., Tittensor, D.P., Davies, A.J., Guinotte, J., Baco, A., Black, J., Hall-Spencer, J.M. & Rogers, A.D. (2012). Global habitat suitability of cold-water octocorals. J*ournal of Bigeography*, **39**, 1278–1292.

Yesson, C., Bedford, F; Rogers, A. & Taylor, M.L. (2015). The global distribution of deep-water Antipatharia habitat. *Deep Sea Research II*, **145**, 79-86.

Zibrowius, H. (1980). Les Scléractiniaires de la Méditerranée et de l’Atlantique nord oriental. *Memoires de l’Institut oceanographique*, **11**, 226.

Appendix A Faunal List for Reef Habitats in Irish Waters

Table 3 Faunal list for reef habitats in Irish waters.

Records limited to taxa visible on high definition video and those identified to at least genus, except for certain fish families that cannot easily be identified to genus without specimens. Record that identifies taxon to lowest level is the one cited. Records without a source citation refer to Allcock unpublished data and draw on ongoing collaboration with taxonomic experts worldwide. Sources: a, Morris *et al*., 2013; b, Huvenne *et a*l., 2011; c, Robert *et a*l., 2015; d, Johnson *et a*l., 2013; e, Le Guilloux *et a*l., 2010.

Taxon	Sessile	Mobile	Source
Phylum Cnidaria			
Class Anthozoa			
Subclass Hexacorallia			
Order Scleractinia			
Caryophyllia spp.	✓		b
Dendrophyllia spp.	✓		
Desmophyllum dianthus	✓		d
Desmophyllum pertusum	✓		b, c
Enallopsammia profunda	✓		
Flabellum spp.	✓		
Javania spp.	✓		
Madrepora oculata	✓		c
Solenosmilia variabilis	✓		c
Stephanocyathus spp.	✓		
Order Antipatharia			
Antipathes dichotoma	✓		
Bathypathes spp.	✓		a
Leiopathes expansa	✓		
Parantipathes hirondelle	✓		
Stauropathes punctata	✓		
Stichopathes gravieri	✓		
Telopathes magna	✓		
Trissopathes spp.	✓		
Order Actinaria			
Actinauge spp.	✓		c
Actinernus michaelsarsii	✓		
Actinoscyphia spp.	✓		d
Pheliactis spp.	✓		
Order Ceriantharia			
Cerianthus spp.	✓		

Taxon	**Sessile**	**Mobile**	**Source**
Order Zoantharia			
Epizoanthus spp.	✓		*d*
Epizoanthus paguriphilus	✓		
Bullagummizoanthus spp.	✓		
Parazoanthus anguicomis	✓		d
Subclass Octocorallia			
Order Alcyonacea	✓		
Acanella spp.	✓		b, c
Acanella cf. arbuscula	✓		a
Acanthogorgia spp.	✓		a, b
Anthomastus grandiflorus	✓		
Anthothela spp.	✓		
Candidella imbricata	✓		
Chrysogorgia spp.	✓		c
Clavularia rudis	✓		
Heteropolypus sol	✓		
Isidella spp.	✓		
Jasonisis spp.	✓		
Keratoisis spp.	✓		
Lepidisis spp.	✓		
Paragorgia ?corallioides	✓		
Paragorgia ?johnsoni	✓		
Paramuricea spp.	✓		
Primnoa resedaeformis	✓		
Radicipes spp	✓		
Swiftia spp.	✓		
Order Pennatulacea			
Distichoptilum gracile	✓		
Halipteris spp.	✓		
Kophobelemnon cf. macrospinosum	✓		
Kophobelmnon stelliferum	✓		
Pennatula aculeata	✓		c
Pennatula cf. grandis	✓		
Pennatula cf. inflata	✓		
Protoptilum spp.	✓		
Umbellula spp.	✓		

Taxon	Sessile	Mobile	Source
Phylum Porifera			
Class Demospongiae			
Axinella spp.	✓		
Geodia macandrewii	✓		
Hexadella dedritifera	✓		d
Hexadella spp.	✓		
Hymedesmia curvichela	✓		d
Lissodendoryx diversichela	✓		
Mycale lingua	✓		d
Stelletta normani	✓		
Stryphnus fortis	✓		
Weberella bursa	✓		d
Class Hexactinellida			
Aphrocallistes beatrix	✓		
Hyalonema stephanocyathus	✓		
Pheronema carpenteri	✓		
Phylum Mollusca			
Class Bivalvia			
Subclass Pteriomorpha			
Order Limida			
Acesta excavata			d
Order Ostreida			
Neopycnodonte zibrowii			d
Class Cephalopoda			
Order Octopoda			
Stauroteuthis syrtensis		✓	
Benthoctopus normani		✓	
Graneledone verrucosa		✓	
Phylum Echinodermata			
Class Crinoidea			
Anachalypsicrinus nefertiti		✓	
Atelecrinus helgae	✓		
Endoxocrinus (Diplocrinus) wyvillethomsoni		✓	
Koehlermetra porrecta	✓		
Neocomatella europaea	✓		
Pentametrocrinus atlanticus	✓		

Taxon	Sessile	Mobile	Source
Class Crinoidea			
Porphyrocrinus thalassae		✓	

Rhizocrinus lofotensis	✓		
Thalassometra lusitanica		✓	
Trichometra cubensis		✓	
Zeuctocrinus gisleni	✓		
Class Echinoidea			
Order Echinothurioida			
Araeosoma fenestratum	✓		
Calveriosoma hystrix	✓		
Hygrosoma petersii	✓		
Phormosoma placenta	✓		c
Sperosoma grimaldii	✓		
Order Camerodonta			
Echinus spp.	✓		
Order Cidaroidea			
Cidaris cidaris	✓		c, d
Class Holothuroidea			
Bathyplotes natans	✓		
Benthogone rosea	✓		
Laetmogone violacea	✓		
Mesothuria spp.	✓		
Parastichopus tremulus	✓		
Psolus squamatus	✓		
Class Asteroidea			
Asteroschema spp.	✓		
Hippasteria spp.	✓		
Nymphaster arenatus	✓		
Peltaster spp. (as Ceramaster spp.)	✓		d
Plutonaster bifrons	✓		
Porania pulvillus	✓		d
Solaster spp.	✓		
Stichastrella rosea	✓		d
Zoroaster fulgens	✓		

Taxon	**Sessile**	**Mobile**	**Source**
Phylum Arthropoda			
Class Malacostraca			
Order Decapoda			
Paramola cuvieri	✓		d
Bathynectes longispina	✓		d

Parapagurus pilosimanus	✓		
Gastroptychus formosus	✓		e
Order Euphausiacea			
Meganyctiphanes norvegica	✓		d
Phylum Chordata			
Class Pisces			
Antimora rostrata (Blue Antimora)	✓		
Bathypterois dubius (mediterranean spiderfish)	✓		
Bathysaurus mollis (Highfin Lizardfish)	✓		
Centroscyllium fabricii (Black Dogfish)	✓		
Coelorinchus caelorhincus (Hollowsnout Grenadier)	✓		
Conger conger (European Conger)	✓		d
Galeus melastomus (Blackmouth Catshark)	✓		
Harriotta raleighana (Narrownose Chimaera)	✓		
Helicolenus dactylopterus (Blackbelly Rosefish)	✓		
Hoplostethus atlanticus (Orange Roughy)	✓		
Hydrolagus mirabilis (Large-Eyed Rabbitfish)	✓		
Lepidion eques (North Atlantic Codling)	✓		d
Lophius piscatorius (Monkfish)	✓		
Maurolicus muelleri (Mueller's Pearlside)	✓		
Melodichthys hadrocephalus	✓		
Neocyttus helgae (False Boarfish)	✓		
Notacanthus bonaparte (Shortfin Spiny Eel)	✓		
Paralepididae spp. (Baracudinas)	✓		
Phycis blennoides (Greater Forkbeard)	✓		
Rajidae spp. (Rays)	✓		
Rhinochimaera atlantica (Broadnose Chimaera)	✓		
Stomias spp. (Barbeled Dragonfish)	✓		

Taxon	**Sessile**	**Mobile**	**Source**
Class Pisces			
Synaphobranchus kaupii (Kaup's Arrowtooth Eel)	✓		
Trachyrincus murrayi (Roughnose Grenadier)	✓		
Trachyscorpia cristulata (Spiny Scorpionfish)	✓		
Phylum Foraminifera			
Order Xenophyophorida			

Syringammina fragilissima		✓	c

Appendix B SAC's designated for Reef Habitats in offshore Irish Waters

Table 4 Special Areas of Conservation within Irish offshore waters designated for Annex I reef habitat. Known reef area indicates the known area of reef habitat within each SAC (Source: NPWS, 2023c).

SAC Name	Location	Date Designated	Area km^2	Known reef area km^2
Porcupine Bank Canyon	Offshore	2012	781	78.6
South East Rockall Bank	Offshore	2011	1,488	149.3
Northwest-Porcupine Bank	Offshore	2009	716	0
Southwest-Porcupine Bank	Offshore	2009	329	0
Hovland Mound Province	Offshore	2009	1,086	0
Belgica Mound Province	Offshore	2009	411	0
Porcupine Shelf	Offshore	2023	14794.42	
Southern Canyons	Offshore	2023	14,434.29	

npws.ie

National Parks and Wildlife Service

Rialtas na hÉireann
Government of Ireland