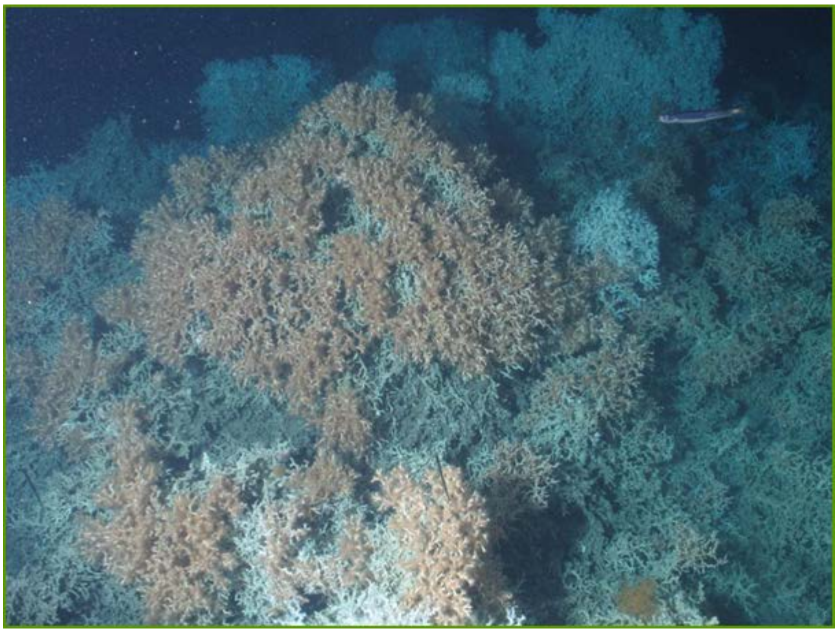
Reef Habitat in Irish Offshore Waters – A synthesis of current knowledge



A report to the Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs

An Roinn Ealaíon, Oidhreachta, Gnóthaí Réigiúnacha, Tuaithe agus Gaeltachta

Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs

Reef Habitat in Irish Offshore Waters – A synthesis of current knowledge

James Forde[1], Louise Allcock[2] & Anthony Grehan[2]

Affiliations:

[1]RPS Group, Lyrr 2, IDA Business and Technology Park, Mervue, Galway.

[2]National University of Ireland, Galway.

Citation:

Forde, J., Allcock, L. & Grehan, A. (2017). *Reef Habitat in Irish Offshore Waters – A synthesis of current knowledge.* A report to the National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Ireland.

Keywords: Biogenic Reef, Geogenic Reef, Habitats, Offshore, Special Area of Conservation (SAC)

Site list: 002327, 002328, 002329, 002330, 003001, 003002

Cover photos: Coral mounds in the Arc Province supporting *Lophelia pertusa* reefs © Fiona Stapleton

The NPWS Project Officer for this report was: david.lyons; david.lyons@ahg.gov.ie

Contents

Abstract i
Acknowledgements i
1 Introduction 1
1.1 Background 1
1.2 Aim and Objectives 2
2 Distribution, Ecology and Biodiversity of Geogenic and Biogenic Reefs 4
2.1 Overview 4
2.2 Key Cold-Water Coral Taxa 4
2.3 Distribution 5
2.3.1 Recorded Distributions 5
2.3.2 Modelled Distributions 9
2.4 Ecology 9
2.4.1 Physico-Chemical Environment 9
2.4.2 Reproductive Biology, Growth Rates and Longevity 12
2.4.3 Population Genetics and Connectivity 15
2.4.4 Community Biodiversity –Faunal Assemblages at Geogenic and Biogenic Reef 16
3 Potential Pressures and Threats 20
3.1 Fishing 20
3.1.1 Fishing Activity Offshore Ireland 20
3.1.2 Fishing Impacts 21
3.2 Climate Change 22
3.3 Pollution/ Litter 23
3.4 Mining and Energy Production 24
3.4.1 Seismic Survey 24
3.4.2 Drilling Operations 25
4 Management and Indicators 27
4.1 Marine Protected Area and Indicators 27
4.2 Risk-Based Management of Fisheries Impacts 27
5 Policy Influencing Protection and Conservation Status 28
5.1 Maritime Spatial Planning Directive 28
5.2 Habitats Directive 28
5.3 Environmental Impact Assessment Directive 29
5.4 Marine Strategy Framework Directive 29

5.5 Strategic Environmental Assessment 30
5.6 EU Deep-Sea Access Regime 30
6 Knowledge Gaps and Recommendations 31
6.1 Conservation Initiatives 31
6.1.1 Special Areas of Conservation 31
6.2 Areas of Future Study 32
6.2.1 Extent and Range 32
6.2.2 Taxonomic Studies 32
6.2.3 Genetic Connectivity of Marine Protected Areas 32
6.2.4 Biotope Classification 32
6.2.5 Ecological Studies 32
6.2.6 Frequency and Effects of Sedimentation Load 33
6.2.7 Water Chemistry 33
7 Bibliography & Relevant Literature 34
Appendix A - Figures 46
Appendix B - Faunal List for Reef Habitats in Irish Waters 78
Appendix C - Goals, Objectives and Indicators for Marine Protected Areas 87

Abstract

The European Union Habitats Directive provides legal protection for a range of habitats and species of European importance listed in the Directive. Under the Directive, member states including Ireland are obliged to introduce measures for the protection and surveillance of the Conservation Status (a measure of the long-term survivability) of habitats and species listed in the Directive. 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 June 2013, Ireland's Department of Arts, Heritage and the Gaeltacht (now the Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs) submitted the second national Article 17 Assessment[1,2,3]. This report identified the area, range, structure, function and future prospects of fifty-eight listed habitats and sixty-one species and evaluated their Conservation Status. Included in this report was a status assessment of the habitat Reef (Habitat Code: 1170).

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 hard substrates on solid and soft bottoms 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, including 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 anemones, sponges, crustaceans and fishes.

It was noted in Ireland's 2013 Article 17 Assessment that there were significant knowledge gaps with regard to offshore reef habitat distribution, extent and ecology, and the potential pressures affecting 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 as required under the next cycle of the Article 17 reporting for the Habitats Directive which is due in 2019.

The specific objectives of this project were to: 1) 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, and 2) create a supporting database of known records.

Acknowledgements

Thanks to project officer David Lyon (NPWS) for support and assistance throughout the study. Thanks are extended to everyone who contributed data to this report and the project GIS database.

[1] NPWS (National Parks and Wildlife Service), 2013a. The Status of EU Protected Habitats and Species in Ireland. Habitat Assessments Volume 1. Version 1.1. Unpublished Report, NPWS. Department of Arts, Heritage and the Gaeltacht, Ireland.

[2] NPWS (National Parks and Wildlife Service), 2013b. The Status of EU Protected Habitats and Species in Ireland. Habitat Assessments Volume 1. Version 1.1. Unpublished Report, NPWS. Department of Arts, Heritage and the Gaeltacht, Ireland.

[3] NPWS (National Parks and Wildlife Service), 2013c. The Status of EU Protected Habitats and Species in Ireland. Habitat Assessments Volume 1. Version 1.1. Unpublished Report, NPWS. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

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. This Directive is enacted through Irish legislation by the European Communities (Birds and Natural Habitats) Regulations (SI 477 of 2011).

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 function, 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 and species listed in Annex I, II and IV 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 the habitats and species and on the implementation of the measures taken under the Directive to ensure their protection.

In June 2013, Ireland's Department of Arts, Heritage and the Gaeltacht submitted the second national Article 17 Assessment. This report identified the area, range, structure and function, and future prospects of fifty-eight Annex I habitats and evaluated their Conservation Status (NPWS, 2013a; 2013b, 2013c). Included in this report was the Annex I habitat Reef (Habitat Code: 1170).

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, 2013a, 2013b). Reef can be broadly categorised based on its mode of origin as geogenic or biogenic (EC, 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 the Irish offshore waters, defined here as continental shelf waters greater than 200 m depth, biogenic reef habitats may be formed by aggregations of 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 and 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 on-going decline (NPWS, 2013a, 2013b).

It was noted in Ireland's 2013 Article 17 Assessment that there were significant data gaps in relation to elements that contributed to the area/ range (spatial data), structure and function, and potential pressure components of the Conservation Status assessment for offshore reef habitats (NPWS, 2013a, 2013b). It was also noted that although significant effort was made to source spatial information, it was considered that not all available sources had been incorporated into the Conservation Status assessment.

1.2 Aim 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 objectives of the project were to:

- **i.** 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, and
- **ii.** create a supporting GIS database of known records.

This desk-study report will contribute towards Habitats Directive Article 17 reporting (due in 2019) for offshore reef habitats and is broadly formatted to align with elements of the assessment of Conservation Status.

This report is structured as follows:

Section 1 Introduction – Provides a background and outlines the main aims and objectives of the project and report.

Section 2 Distribution, Ecology and Biodiversity of Geogenic and Biogenic Reefs (Including Carbonate Mounds) – Outlines the ecological setting, distribution and structure of reef habitat and associated communities in Irish offshore waters.

Section 3 Potential Pressures and Threats – Provides an account of the predominant anthropogenic pressures impacting habitat structure and function. This section also introduces some potential indicators of structure and function.

Section 4 Management and Indicators – Provides summary information of tools that could be applied in the development and management of reef habitats.

Section 5 Policy Influencing Protection and Conservation Status – Summarises the main policy drivers influencing the conservation of reef habitats.

Section 6 Knowledge Gaps and Recommendations – This section presents recommendations for the future conservation of offshore reef habitats. This section also discusses significant gaps in the ecological understanding of offshore reef.

Section 7 References – Records and ecological references relating to offshore reef habitats occurring within Irish waters.

Appendices

Appendix A Figures

Appendix B Faunal List for Reef Habitats in Irish Waters

Appendix C Goals, Objectives and Indicators and Success Criteria for the Management of Cold-water Coral Marine Protected Areas

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).

In the Irish offshore (waters greater than 200 m in depth) biogenic reef habitats are 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 and Leahy, 2009; Johnson et al., 2013).

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, the species commonly known as *Lophelia pertusa*[4]. 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, if not wholly, 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 (e.g., Johnson et al., 2013).

Section 2.2 below provides a summary description of the major cold-water coral taxa, while **Section 2.3** describes their distribution globally and within Irish offshore waters. **Section 2.4** describes the ecological conditions that control the occurrence and distribution of cold-water coral species.

Both biogenic and geogenic reefs 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 fishes (NPWS, 2013a, 2013b). **Section 2.4** below provides summary descriptions of community taxa associated with biogenic and geogenic reef.

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 2.1**). Biogenic reef occurs as three distinct bedforms: small stands of coral, extensive reef structures and coral carbonate mounds; the latter being formed by multiple generations of reef

[4] *Lophelia pertusa* has recently been moved to the genus *Desmophyllum* (as *D. pertusum*) following molecular work (Addamo et al., 2016), but since this nomenclatural change has not yet been incorporated into the World Register of Marine Species, we retain the previous combination in this work.

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, 2013b; Roberts et al., 2006, 2009; Rogers, 1999; Tyler and Zibrowius, 1992). Reef structures also often support an array of Antipatharia species including *Cirrhipathes sp*., *Leiopathes sp*., *Parantipathes sp*., *Stichopathes gravieri*, and Octocorallia (soft) coral species including *Anthomastus grandiflorus*, *Paragorgia arborea*, *Paramuricea spp*., *Anthothela spp*. and isidid 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 2.1: Classification of major cold-water reef-forming taxa in Irish offshore waters (in bold) (modified from Cairns, 2007, Roberts et al., 2009 and the World Register of Marine Species[5]).

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 Distributions

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* Duncan, 1873. 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.*

[5] http://www.marinespecies.org/aphia.php?p=browser&id=16352&expand=true#ct

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 **Appendix A Figure A.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[6] 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 (**Figure A.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 and Roberts, 2013). *Lophelia pertusa* forms bush-like colonies (**Figure A.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 (**Figure A.4**) (OSPAR, 2009; Roberts et al., 2009).

Madrepora oculata is widely distributed in the Atlantic and Pacific Oceans (**Figure A.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 A.6 shows the distribution of *Madrepora oculata* in Irish offshore waters based on direct observations recorded in published and online sources[7]. *Madrepora oculata* reef structure (see **Figure A.7**) is more fragile than that of *Lophelia pertusa*, and does not 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 A.8** shows global distribution of *Solenosmilia variabilis* in the 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.). *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 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 and climate change and trawling.

Six SACs outside of territorial waters have been designated for the protection of biogenic and/ or geogenic reef habitat. The distribution of these offshore SACs is illustrated in **Figure A.9.** The scleractinian species *Lophelia pertusa* and *Madrepora oculata* are the major reef-forming species of the Belgica Mound Province SAC (NPWS, 2014a) and North-west Porcupine Bank SAC (NPWS, 2014b), and are found to form patch reefs in the Hovland Mound Province SAC (NPWS, 2014c). *Lophelia*

[6] See project GIS database for sources

[7] See project GIS database for sources

pertusa has been identified as the major framework species at the South-west Porcupine Bank SAC (NPWS, 2014d) while *Solenosmilia* variabilis has been identified at the South-east Rockall Bank SAC (NPWS, 2014e).

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 corals form un-branched whips and bush-like colonies (**Figure A.10**) which can reach up to 3 m in height. Black corals 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[8] black corals 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 A.11**). Black coral species found in Irish offshore waters include *Parantipathes hirondelle*, *Trissopathes sp*., *Bathypathes* sp., *Leiopathes expansa*, *Antipathes dichotoma*, *Stichopathes gravieri*, *Stauropathes punctata*, *Telopathes magna*, *Cirrhipathes sp*., *Parantipathes sp*. and *Stichopathes gravieri* (Allcock et al., 2016; OSPAR, 2010). Black corals are listed as important community characterising species at the South-east Rockall Bank SAC (NPWS, 2014e) and Porcupine Bank Canyon SAC (NPWS, 2014f) (**Figure A.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[9] indicate that octocorals are widely distributed in waters off Ireland, extending from the Rockall Bank to the Atlantic continental slope margin and the canyon complexes to the south of the Porcupine Basin and Goban Spur (see **Figure A.12**). Octocoral species have are found at the Belgic Mound Province SAC (NPWS, 2014a) and South-east Rockall Bank SAC (NPWS, 2014e) (**Figure A.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 Belgica Mound Province

[8] See project GIS database for sources
[9] See project GIS database for sources

SAC (NPWS, 2014a), Hovland Mound Province SAC (NPWS, 2014c), South-east Rockall Bank SAC (NPWS, 2014e) and Porcupine Bank Canyon SAC (NPWS, 2014f) (**Figure A.9**).

2.3.1.5 Carbonate Mounds

Coral carbonate mounds are distinct features that are formed over timescales of 1 to 2 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[10] 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 A.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 characterized 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 km.

The Arc Mound Province, situated on the south-western margin of the Porcupine Bank, comprises 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) (**Figure A.14**). A number of the carbonate mounds in the region have been shown to support extensive colonies of *Lophelia pertusa* (**Figure A.15**).

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

[10] See project GIS database for sources

Porcupine Seabight, in water depths from 300 m to 500 m (Wilson et al., 2007) (**Figure A.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 habitat.

2.3.2 Modelled Distributions

Due to the inherent difficulty and expense associated with surveying deep-water ecosystems, knowledge of the true extent of coral distributions and indeed 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 and Howell, 2013; Yesson et al., 2012, 2015). These modelled distribution maps are useful to managers working to 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 et al., 2012). **Figure A.17** to **Figure A.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 current and dissolved oxygen.

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 A.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 characterized as an increase in surface temperatures from approximately 4°C to 6°C (Holliday and Cunningham, 2013). The other important component of the north-east Atlantic circulation is the Mediterranean Outflow Water (MOW) (Holliday and Cunningham, 2013; White, 2007; White et al., 2005) which forms the major intermediate water mass. The MOW is characterized by an increase of 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 and 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 northwestern branch of ENAW and North Atlantic Waters as well as from fresher, modified North Atlantic Water, the SAIW from the north and west (Lankhorst and Zenk, 2006). Detached pockets of MOW reach the western Rockall Bank at water depths between 800 m and 1100 m (Harvey, 1982). Beneath these pockets lies 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[11] (δΔ) = 27.35 to 27.65 kg/ m^3 (see **Figure A.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 and include local current strength and 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 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).

[11] Conductivity and temperature are first used to compute salinity, which is then combined with potential temperature to compute the potential density anomaly (δΔ = sigma-theta).

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 and 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.

Recently, 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.

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 while Wilson (1979) and, Wilson and 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 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 margin seabed consisting of tens to hundreds of kilometres long, narrow valleys, carved tens to hundreds of meters deep into the margin, often extending 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 A.22**). Given that the few canyon areas that have been investigated by remotely operated vehicles (ROV) 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.

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 and Tyler, 2005). The dominant strategy for reproduction appears to be broadcast spawning whereby gametes are released to the water column, where fertilization 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 and 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 production of gametes in *Lophelia pertusa*. This gamete growth continues in *Lophelia pertusa* until the gametogenic cycle is completed. According to Waller and Tyler (2005), broadcast spawning takes place in January/ February.

While *Lophelia pertusa* appears to exhibit seasonal reproduction, Waller and 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 observations in the laboratory. Embryos developed in a more or less organized 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 6 - 8 hours up to the 64-cell stage. Larvae were active swimmers (0.5 mm/ second) initially residing in the upper part of the water column, with bottom probing behaviour starting 3 – 5 weeks after fertilization. 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 basically three types of scleractinian larvae: buoyant larvae that rise to the sea surface, neutral larvae that drift with the current staying submerged, negatively buoyant and crawling larvae. The late onset of competency and larval longevity observed by Larsson et al. (2014), suggests a high dispersal potential although 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 A.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.).

Alcyonacea genera listed by Freiwald et al. (2004) as potentially habitat-forming 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 specialized 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 and 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. 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).

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

The little that is known about 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 fertilization has not been identified in any of the studied specimens and fertilization 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.

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 northeast Atlantic indicate growth rates range between 5 to 34 mm/ year (Duncan, 1877; Wilson, 1979; Bell& Smith, 1999; Roberts, 2002; Gass & Roberts, 2006) while laboratory aquaria observation suggest growth rates vary between 15 and 17 mm/ year (Orejas et al., 2008). In the case of *Madrepora oculata* maintained in aquaria growth rates ranged between 3.0 and 18 mm/ year.

Octocorals tend to be long lived, with colony ages generally in the tens to hundreds year range, with much variation in estimates. Focusing only on deep-sea samples, *Paramuricea* colonies have been found to survive 599 years (Prouty et al., 2006), *Chrysogorgia* to 464 years (Prouty et al., 2006), *Primnoa* to more than 300 years (Risk et al., 2002), *Paragorgia* to 80 years (Sherwood and Edinger, 2009). Among bamboo corals, *Acanella* has been found to live to 100 years (Sherwood and Edinger, 2009), *Isidella* to 53 years (Andrews et al., 2009) and *Lepidisis* to 45 years (Sherwood and Edinger, 2009). Younger dates have also been obtained and dates probably vary by depth, water temperature, species and even methodology. 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 and 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 great longevity and to be slow growing. The former particularly because of the estimate that specimens of *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 ^{230}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 and Edinger, 2009). Naturally extreme ages are mirrored by extremely slow growth. Reported radial growth in *Leiopathes* species varies between 0.005 and 0.02 mm/ year. In other species radial growth of 0.04 to 0.66 mm/ year translated to vertical growth of 1.22 to 1.36 cm/ year, growth of 0.1 mm/ year translated to vertical growth of 1.3 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 and Smith, 1999; Gass and 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 homogenetic distribution while *Madrepora oculata* has a much more heterogeneous pattern (**Figure A.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.

Very little work has been conducted on deep-water antipatharians or alcyonaceans to date although several studies are currently being undertaken in the US. Some species of black coral seem to maintain panmixia across ocean expanses, e.g., *Stichopathes filiformis*, while others show distinct genetic structuring and assymetric gene flow over varying spatial and bathymetric scales, e.g., *Antipathes robillardi* and *Stichopathes variabilis* (Miller et al., 2010). No data have yet been published from Irish waters, although some DNA samples from Irish specimens have been shared with US researchers to explore connectivity from the Western to Eastern Atlantic.

2.4.4 Community Biodiversity –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, 2013b; OSPAR, 2010a; Roberts et al., 2006, 2008; Sumina and 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 and 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 B Table B.1**.

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 starfishes, sea urchins, polychaetes, crustaceans and fishes (Freiwald et al., 2004; NPWS, 2013a, 2013b; OSPAR, 2010; Roberts et al., 2006, 2008; Sumina and 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 and Roberts, 2007; Jensen and 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, 2009. Commonly associated species include invertebrates such as echiurans (e.g. *Bonellia sp*.), molluscs (e.g. *Acesta excavata*), shrimp (*Pandalus spp*.), squat lobsters (*Munida spp*.) and echinoderms such as pencil sea urchins *Cidaris spp*. and basketstars *Gorgonocephalus sp*. (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 ophuiroid 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 macrofauna communities (Wheeler et al., 2005; Weinberg et al., 2008; OSPAR, 2010). On the Franken Mounds on the Rockall Bank, Weinberg 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 (actinarians). Dense coral reef habitats predominately consist of live and dead scleractinians, octocorals, actinarians and sponges. Coral debris fields have been found to support two distinct assemblages of sponges and cnidarians growing on *Lophelia sp.* 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 and 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 and 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* sp. nov., *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 colonized by squat lobsters (*Munida sp.*) living on coral rubble, whilst the inter-mound areas consist of soft sediments, often colonized by anemones. Furthermore, Husebø et al. (2002) reported squat lobsters abundance to be 10 times higher in coral habitat than the surrounding seabed. Whether or not 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, 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 and Rogan, 2006). A number of fish species, including *Brosme brosme* (tusk), 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), suggesting 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 (MaxN) between coral and reference stations as indicators of local fish density at a number of European sites including the Belgica Mounds. Fish reached significantly higher MaxN 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 sp.* (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 and 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 and Quattrini (2007) during a study off the south-eastern United States, reported that several fish species spent long periods totally 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 and 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 and Mortensen, 2004; Edinger, 2007; Söffker et al., 2011; Stone, 2006; Wagner, 2012).

Davies et al. (2013) 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*, included elements of biogenic reef. The *Lop.Hal* biotope comprised live and dead *Lophelia pertusa* providing habitat for burrowing and tube anemones and substrate for *Madrepora oculata,* Acanella, ascidians and crinoids while the *Lop.Cri* biotope comprised live and dead *Lophelia pertusa*, providing habitat for *Psolus squamatus*, *Stichopathes* sp. and crinoids. A third reef biotope (*Bat.Hyd*) comprised *Bathylasma* (balanomorph 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, 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 graden 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 *Lophelia pertusa* (Huvenne et al., 2011). Apart from these two well-described habitats, geogenic reefs occur wherever there is exposed bed rock.

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 presumably 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* sp., *Lophelia* sp., *Madrepora* sp., *Desmophyllum* sp., *Anthomastus* sp., 2 x *Paragorgia* spp., *Radicipes* sp., *Acanthogorgia* sp., *Primnoa* sp., *Kophobelemnon* sp., *Umbellula* sp., *Anthoptilum* sp.), nine to family level (8 x Isididae spp., 1 x Stylasteridae sp.), four to Order (3 x Alcyonacea, 1 x Pennatulacea) and two simply as 'purple coral' and 'peach single polyp'. The species list provided in **Table B.1**, is thus 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., 2014) 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 and 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 unpublished data (Allcock, unpublished).

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 because of differences in sampling intensity and method. Nonetheless, it is becoming increasingly clear that deep-water geogenic reefs can be highly diverse. Certainly, where coral species are abundant and dense, they greatly increase biodiversity through 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 generally see Buhl-Mortensen and 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 more 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 A.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). Interaction 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 mound 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, 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 included 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 was 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 used trawls, gill nets, and tangle nets as well as long-lining. In the early 2000s, a small number of Irish vessels successfully targeted orange roughy spawning aggregations with catches increasing from three metric tonnes in 2,000 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 focussed. 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*.

Static gears deployed in the vicinity of cold-water coral reefs 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, again 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 and 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; Söffker et al., 2011; Hall-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 3.1**.

Table 3.1: Potential severity of fishing métier impacts on corals (from Grehan et al., 2005).

Métier	Ranking
Trawling	High importance
Longlining	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 30 2016 will give some protection below this depth (see **Section 5**), although it is likely that trawl-accessible areas below this depth on the Irish shelf edge have already been irrevocably damaged.

The periphery and interfluvial ridges of submarine canyons are increasingly targeted by fisheries (Martín et al., 2014a). 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. Black corals particularly, due to their preference for low sediment cover, susceptibility to abrasion (Wagner, 2012) and inability to withdraw their polyps, are likely to be particularly 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 long lines and other fishing gear has been seen in Whittard Canyon and other canyons on the Irish continental margin (Allcock, unpublished, **Figure A.24**). Huvenne et al. (2009) illustrate corals entangled in a lost long line in Whittard Canyon.

3.2 Climate Change

Climate change may impact offshore coral reef systems in at least two ways (Guinotte, 2006; Hennige et al., 2014, 2015; Orr et al., 2005; 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.

Recent 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. Orr et al., 2005), which may affect deep-water coral distribution and growth (Guinotte, 2006; 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 truly appreciate 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 that 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 that the aragonite saturation horizon was 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 4m/ 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 measureable 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 acclimatize to multiple stressors of temperature and CO_2, but that significant changes happen to its skeletal biomineralization, molecular-scale bonding and structure resulting in the exposed coral framework, which forms the structural base of cold-water coral reefs, becoming 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 acclimatize in the short term and that strategies to reduce CO_2 emissions are still needed to minimize 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, 2014b). Examining data from 588 video and trawl surveys across 32 sites in European waters, Pham et al. (2014a, 2014b) found litter 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.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.

A study undertaken as part of the EC CoralFISH project investigated litter at three mound provinces in Irish offshore waters: Logachev Mounds, Arc Mounds and Belgica Mounds (see **Figure A.25**) (CoralFISH, 2013). At each mound province, three areas in coral (on mound) and in non-coral (off mound) were randomly selected. Within each area a standardized 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 (**Figure A.26**) are visible which have been immersed for different durations as evidenced by the degree of epifaunal fouling. Some displacement of corals is apparent where snagged nets have been dragged through and outside of reef areas (**Figure A.26**).

While microplastics are increasingly recognized 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.

3.4 Mining and Energy Production

The Irish Offshore Operators Association (IOOA) held a workshop on the theme of '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 coral distribution and the interaction of anthropogenic activities.

3.4.1 Seismic Survey

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 – 30 m) Hastings et al. (2008) found 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 (Laarson 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 reefs-associated species would cause short- or long-term adverse biological impacts. This conclusion was based on potential peak level 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., (2014) which indicated no significant impact of sound on benthic communities. Similarly, based on the findings of Andriguetto-Filhoa et al. (2005) and sound levels modelled for Irish cold-water corals, impacts on invertebrates such as shrimp species are 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 programs 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, was extremely valuable in defining the connectivity and coral recruitment dependence between regional 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

4.1 Marine Protected Area 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 A.27**). As part of the PROTECT project, Goals, Objectives, Indicators and Success Criteria (GOIS) tables were devised for three case studies including cold-water corals (see **Appendix C Table C.1.**). Goals and objectives for MPAs are categorized into three broad types: biophysical, socio-economic and governance. Indicators were then assigned to these goals and objectives. Definitions for indicators as well as a detailed narrative of methods of measurement and guidance on analysis interpretation of results are provided in Pomeroy et al. (2004).

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 (VME) (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 A.28**) within areas of known and predicted coral habitat (see **Figure A.29**). 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 a low risk. The spatial distribution of risk, shown in **Figure A.30**, then forms the basis for the recommendation for fisheries management actions (CoralFISH, 2013).

5 Policy Influencing 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, Planning, Community and Local Government. The regulation was transposed into Irish law on September 18th, 2016 (European Union (Framework for maritime Spatial Planning) Regulation 2016 (SI 352 of 2016). Under the provisions of the Directive Ireland must develop and implement a national Marine Spatial Plan by March 2021. While the detail on the objectives, strategy and implementation of the national plan have yet to be finalised, a recent research project, commissioned by the Irish Environmental Protection Agency (EPA, 2016), has outlined recommendations for the preparation of the national marine plan. This report recognises the need for an integrated approach to the development of the national marine plan and the need to take into account existing environmental legislation. Legislation of particular relevance to the protection that must be integrated into account the national marine plan includes;

- The Habitats Directive (see **Section 5.2**),
- The Environmental Impact Assessment (EIA) Directive (see **Section 5.3**),
- The Marine Strategy Framework Directive (MSFD) (see **Section 5.4**) and,
- The Strategic Environmental Assessment (SEA) Directive (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 interest through the establishment of SACs. To date Ireland has designated six SACs for the protection of biogenic and/ or geogenic reef outside of its territorial waters (see **Appendix B** for site synopsis reports for each SAC). The establishment of SACs may include the establishment of objectives or targets, or management plans to ensure the protection of qualifying feature for which the site is designated.

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 an 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 may only be permitted where a likely significant adverse effect can be ruled out. In the case where negative impacts cannot be mitigated or eliminated 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 Assessment 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, all of which are codified within Directive 2011/92/EU of 13th December 2011. The EC has recently proposed additional amendments to the Directive (European Commission, 2012) 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.

The Directive's main aim is to ensure that specified types of project, which are 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 are 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.

Ireland's MSFD Initial Assessment (Marine Institute, 2013) reported that, because of their depth, remoteness, and considerable extent, deep-water habitats in Irish offshore waters are not well characterised. Due to this lack of knowledge it was concluded that it was not possible to undertake comprehensive assessment of habitat status. It was reported, however, that the condition of many reef complexes in the Irish offshore are likely to be adversely affected by anthropogenic activities, in particular bottom fishing activity. As part of the on-going MSFD process Ireland is developing targets and indicators 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/ water management, 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 Communication Energy and Natural Resource has undertaken a series of national regional environmental assessments (IOSEA 1 – IOSEA5) to underpin hydrocarbon exploration activities. As part of the SEA process the potential effects of hydrocarbon exploration on 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 of commencement of 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. The agreed draft regulation aims to ensure the sustainable exploitation of deep-sea stocks while reducing the environmental impact of these fisheries. The agreement introduced a number of innovative tools to manage the stocks including:

- an 800 meter depth limit below which it will not be possible to fish with bottom trawls,
- the setting of 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, and
- special protection measures for vulnerable marine ecosystems which apply to operations with bottom gears below a depth of 400 m,

All of these measures should reduce the potential fishing impacts on cold-water coral habitats in Irish waters.

6 Knowledge Gaps and Recommendations

6.1 Conservation Initiatives

6.1.1 Special Areas of Conservation

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 analysis of the Irish National Seabed Survey bathymetry (see **Figure A.17**). This model was used to predict the distribution of *Lophelia* in Irish waters 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.

It is evident that the existing designated SACs cluster in the central portion of the predicted reef distribution and may not encompass the likely bio-geographical variability of the reefs' associated fauna. In addition, the model predicts 2% (approximately 7,000 km^2) of the study area (Irish EEZ) to be suitable habitat with only a proportion occurring within existing SACs.

Rengstorf et al. (2013) suggest that the existing Natura network may be improved by inclusion of additional protected areas to facilitate gene flow between coral areas. Those authors have suggested additional potential sites to the north, west and south of the existing SACs (**Figure A.17**). Consideration of the conservation value of those sites could not be undertaken without targeted research surveys and associated scientific work on population connectivity and larval dispersal. .

Ross (2016) investigating the development of an 'ecologically coherent' network of deep-sea marine protected areas using larval dispersal models found that the Irish marine protected area network could be improved in terms of connectivity between protected areas. Ross (2016) reported that the large area of Irish continental margin which remains outside of the network (**Figure A.27**) would benefit from further protective measures, particularly between Porcupine Bank and the Barra Fan and Hebrides Slope in UK waters. This also agrees with recommendations made by Rengstorf et al. (2013) derived from their high resolution *Lophelia pertusa* reef model.

Ross (2016) recommended the Whittard Canyon near this region as a potential area for protection but indicated that the complex topography of canyon features may be more conducive to larval retention rather than larval exchange. 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 the Rockall Trough and the southern Hatton Rockall Basin. Any site that would be considered would have to satisfy the criteria for designation and would have to be sufficiently large to encompass a significant proportion of the national resources.

While Ireland has claims to an Extended Continental Shelf area that contains valuable coral reef resources, the Habitats Directive is currently not applied in this area. Only the NEAFC (North East Atlantic Fisheries Commission) have provided any protection to coral habitats in waters outside and to the west of the Irish EEZ. Should conservation of *Lophelia pertusa* be supported in these deeper marine protected areas in the future, Ireland may wish to consider the Fangorn Bank as a potential area for future protection also. This site offers the only potential to improve connections to Edoras

Bank (Ross, 2016). Further work is required including biological ground-truthing to compare predictions to population genetics in the region.

6.2 Areas of Future Study

6.2.1 Extent and Range

The most significant survey effort of areas likely to harbour geogenic reefs in Irish waters has been in Whittard Canyon. There are considered to be more than 50 canyon systems on the Irish continental margin. Depending on topology, these may be more or less likely to harbour geogenic reef although many are likely to be overlaid with a superficial sediment layer which would limit the formation of reef habitat. 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, but it is important that Ireland is part of these studies so that we 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 produced a detailed description of the different cold-water coral habitat types encountered in European seas including off the west coast of Ireland (CoralFISH 2013). 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 recognized. It is recommended that this catalogue is used to develop recognisable biological communities for the different coral biotopes present in Irish waters. In addition it is recommended that all Irish coral records be notified 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 scleractinia and species of the black coral genera Trissopathes, Bathypathes, Stauropathes and Leiopathes and the alcyonacean genera Paragorgia, Paramuricea, Primnoa, Isidella and 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 sediment load. 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. It is likely as previously noted that sediment resuspension is a feature of other canyon systems in Irish waters.

6.2.7 Water Chemistry

Monitoring of water chemistry is needed to monitor ocean acidification and the speed of aragonite saturation horizon shallowing (see **Section 2.4.1** above).

7 Bibliography & Relevant Literature

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.

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. In press. http://dx.doi.org/10.1016/j.pocean.2016.06.003

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 210Pb 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.

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].

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 [BSc: 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 modeling tools for ecosystem base management in the deep waters of Europe and beyond, EU FP7 Large-scale integrating project no. 213144 Final Periodic Report. 193 pp.

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, pp. 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=EN

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

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

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 environmental policy. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN

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

Council Directive (2014). Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0089&from=EN

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 I, 55, 1048–1062.

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 (Department of Environment Community and Local Government) (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/DevelopmentandHousing/Planning/FileDownLoad,32720,en.pdf

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, 1–164.

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. (1877). 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.

EC (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

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.

EPA (Environmental Protection Agency) (2016). Towards an Integrated Policy Framework for Maritime Spatial Planning in Ireland: Recommendations for Preparing Maritime Spatial Plans in Ireland https://www.epa.ie/pubs/reports/research/water/EPA%20RR%20174%20prepress%20final%20web%20with%20covers.pdf

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, 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. 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, 2005, Bethesda, Maryland, p. 819-832.

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 (International Council for the Exploration of the *Sea*) Annual Science Meeting, Vigo p. 1-9.

GuillouxE, Hall-Spencer, J. M., Sofffker, 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.

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. 193 pp.

Guinotte, J. M. (2006). Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? Frontier Ecology Environ.

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.

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, 507-511.

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.

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.

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

Howell, K. L. (2010). A benthic classification system to aid in the implementation of marine protected area networks in the deep/high seas of the NE Atlantic. Biological Conservation, 143, 1041–1056.

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.

Hovland, M. & Thomsen, E. (1997). Cold-water corals- are they hydrocarbon seep related? Marine Geology, 137, 83–96.

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., 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., 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 sidescan sonar and ROV seabed mapping.

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.

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

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

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.

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).

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).

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.

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.

Marine Institute (2013). Ireland's Marine Strategy Framework Directive Article 19 Report Initial Assessment, GES and Targets and Indicators. Marine Institute, pp. 1–129.

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 Research 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.

Miller, K., Williams, A., Rowden A. A., Knowles, C., & Dunshea, G. (2010). Conflicting estimates of connectivity among deep-sea coral populations. Marine Ecology, 31, 144–147.

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.

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. 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.

Mortensen, P. B., Hovland, M., Brattegard, T. & Farestveit, R. (1995). Deep water bioherms of the scleractinian coral *Lophelia pertusa* (L.) at 64^{o}N on the Norwegian shelf: structure and associated megafauna. Sarsia, 80, 145–158.

NPWS (National Parks and Wildlife Service) (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

NPWS (National Parks and Wildlife Service) (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

NPWS (National Parks and Wildlife Service) (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

NPWS (National Parks and Wildlife Service) (2014a). Site Synopsis. Site Name: Belgica Mound Province SAC. Site Code 002327. Rev13. Ver. 06.01.2014. https://www.npws.ie/sites/default/files/protected-sites/synopsis/SY002327.pdf

NPWS (National Parks and Wildlife Service), 2014b. 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

NPWS (National Parks and Wildlife Service) (2014c). 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

NPWS (National Parks and Wildlife Service) (2014d). Site Synopsis. Site Name: South-west Porcupine Bank SAC. Site Code 002329. Rev13. Ver. 09.01.2014. https://www.npws.ie/sites/default/files/protected-sites/synopsis/SY002329.pdf

NPWS (National Parks and Wildlife Service) (2014e). 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

NPWS (National Parks and Wildlife Service) (2014f). Site Synopsis. Site Name: Porcupine Bank Canyon SAC. Site Code 003001. Rev13. Ver. 10.02.2014. https://www.npws.ie/sites/default/files/protected-sites/synopsis/SY003001.pdf

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. 32 pp.

OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) (2010). Background Document for Carbonate Mounds. Biodiversity Series. 21 pp.

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.

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.

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).

Pomeroy, R.S., Parks, J.E. & Watson, L.W., 2004. How is your MPA doing? A guidebook of natural and social indicators for evaluating marine protected area effectiveness. IUCN – Gland, Switzerland and Cambridge, UK. 216pp; see www.effectivempa.noaa.gov/guidebook/guidebook.html

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. 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 Part II: Topical Studies in Oceanography, 129, 196 – 212.

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.

Puig, P., Canals, M., Company, J. B., Martín, J., Amblas, D., Lastras, G., Palanques, A. & Calafat, A. M. (2016). 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. PNAS 111, 8861–8866

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. Caribbean Journal of Science, 47, 13–30.

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

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.

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.

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., Fallon, S. J. & Mucciarone, D. A. (2009). Extreme longevity in proteinaceous deep-sea corals: Proceedings of the National Academy of Sciences. 106, 5204–5208.

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.

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. ISBN: 9780521884853

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. Chapter 8 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, 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. (2016). Investigating the role of larval dispersal models in the development of an 'ecologically coherent' network of deep-sea marine protected areas. PhD Thesis: University of Plymouth, UK. http://hdl.handle.net/10026.1/6560.

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: 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 *In Press*.

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.

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. (2013), A Geological and Geophysical Description of the Arc Mounds, southwest Porcupine Bank [MSc 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. and Akhmetzhanov, A.M., (Eds) Cold water carbonate mounds and sediment transport on the Northeast Atlantic margin. Intergovernmental Oceanographic Commission Technical Series, 52. UNESCO 1998.

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

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, 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., 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.

Yesson, C., Bedford, F; Rogers, A. & Taylor, M. L. (2015). The global distribution of deep-water Antipatharia habitat. Deep Sea Research II In press doi:10.1016/j.dsr2.2015.12.004.

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. Journal of Biogeography, 39, 1278 – 1292.

Zibrowius, H., 1980. Les Scléractiniaires de la Méditerranée et de l'Atlantique nord oriental. Memoires de l'Institut oceanographique No 11, 226.

Appendix A - Figures

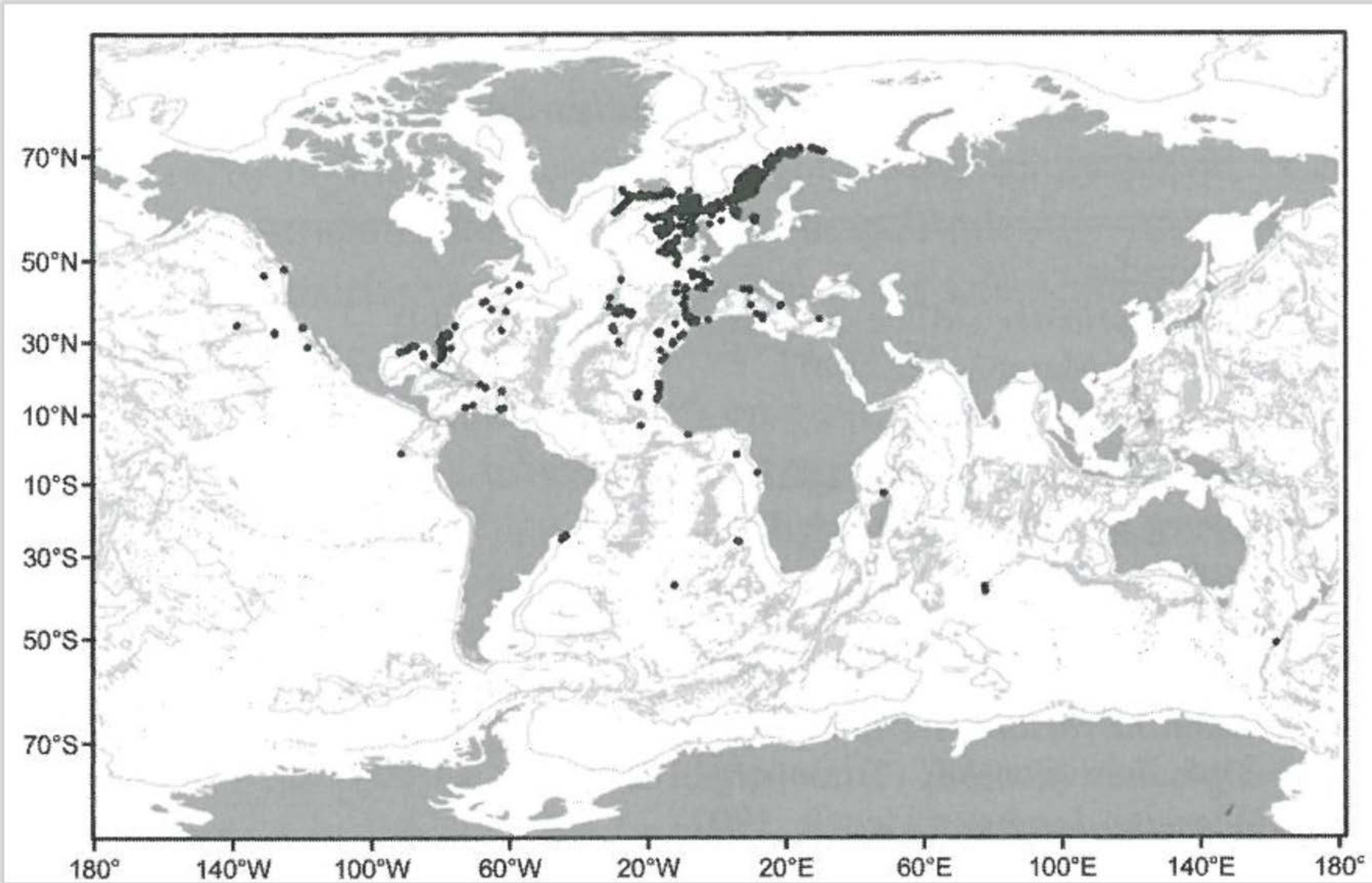


Figure A.1: Map showing the global distribution of *Lophelia pertusa* (●) (from Roberts et al., 2009) (isobaths at 2,000 m, 5,000 m and 9,000 m)

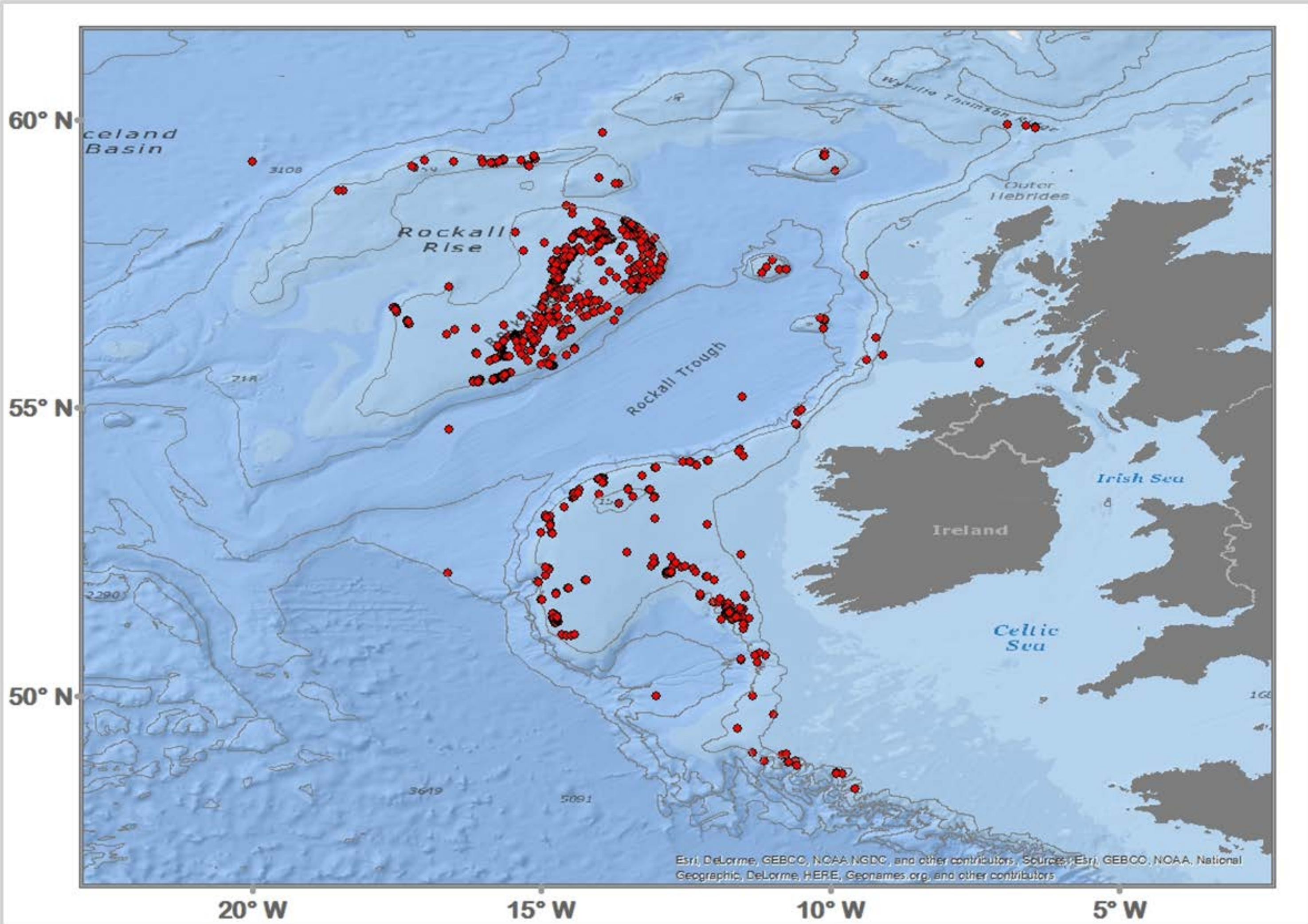


Figure A.2: Map showing the distribution of *Lophelia pertusa* (●) in Irish offshore waters based on direct observations recorded in published and online sources (see Project GIS Database). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

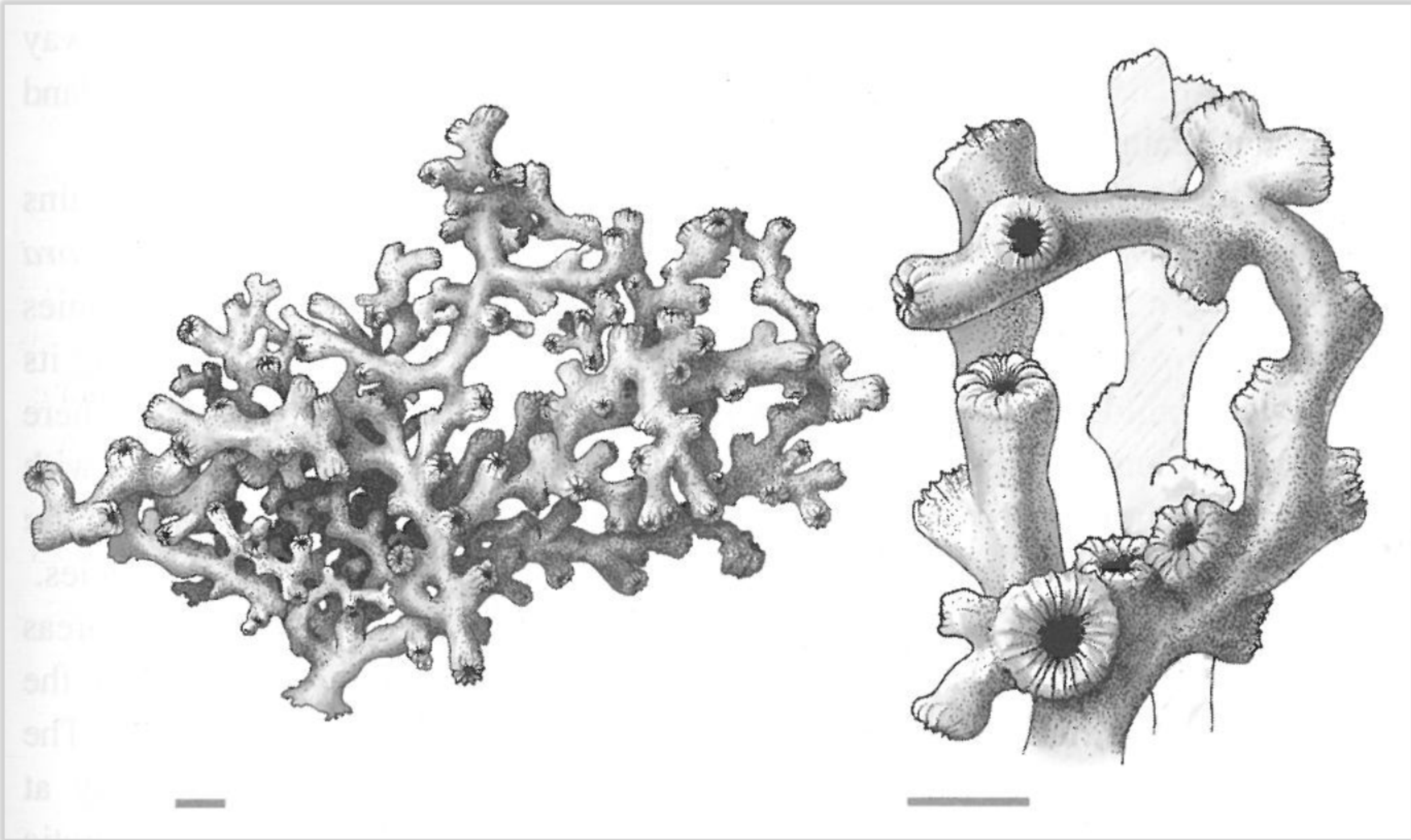


Figure A.3: Drawing of Lophelia pertusa skeleton showing framework formed by the coral colony and details of individual polyp (from Roberts et al., 2009). Scale bars 10 mm (colony) and 10 mm (polyp detail).

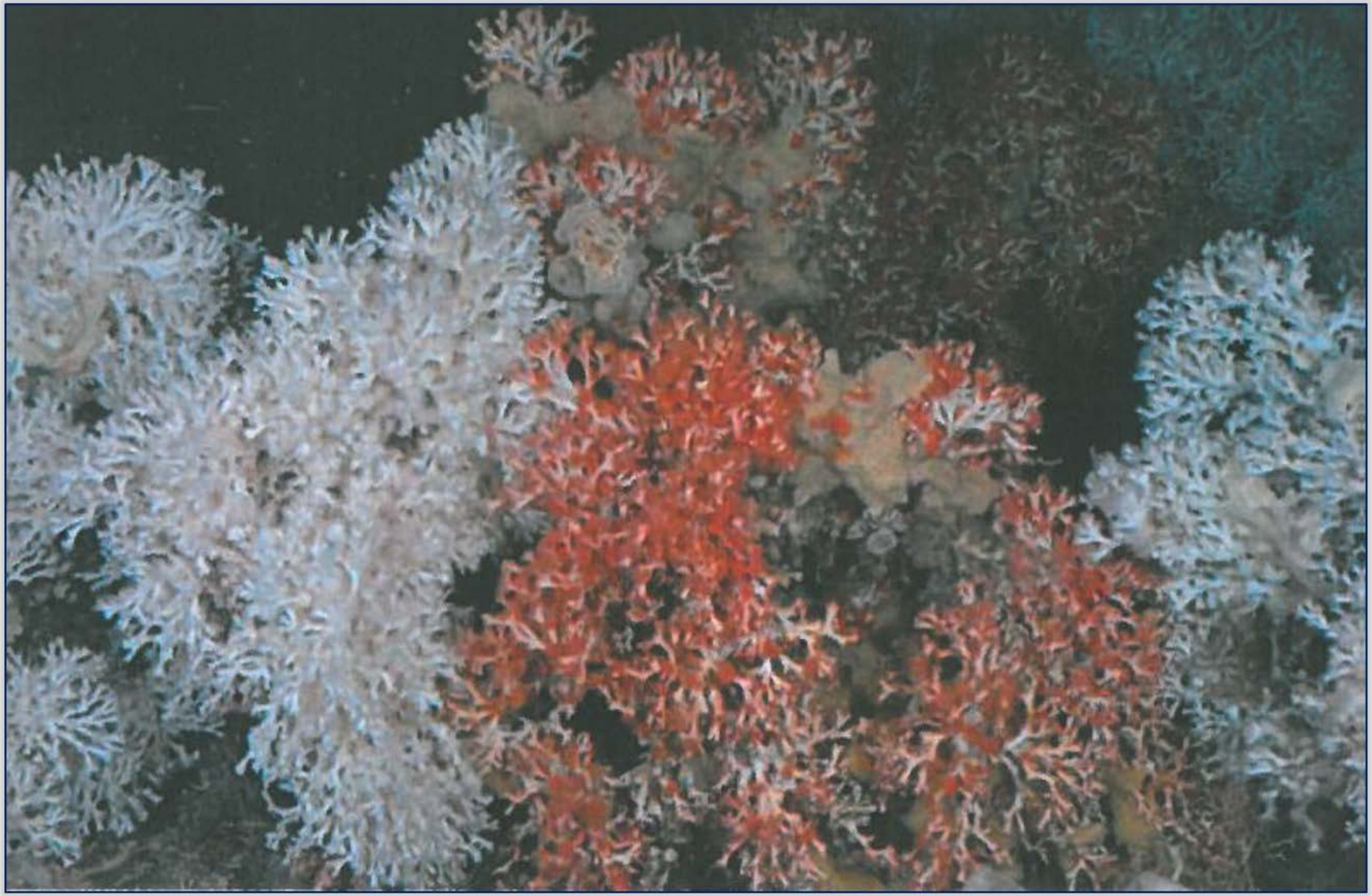


Figure A.4: ***Lophelia pertusa*** **reef (showing white and orange morphs) at 400 m depth off Rost, Norway (from OSPAR, 2009).**

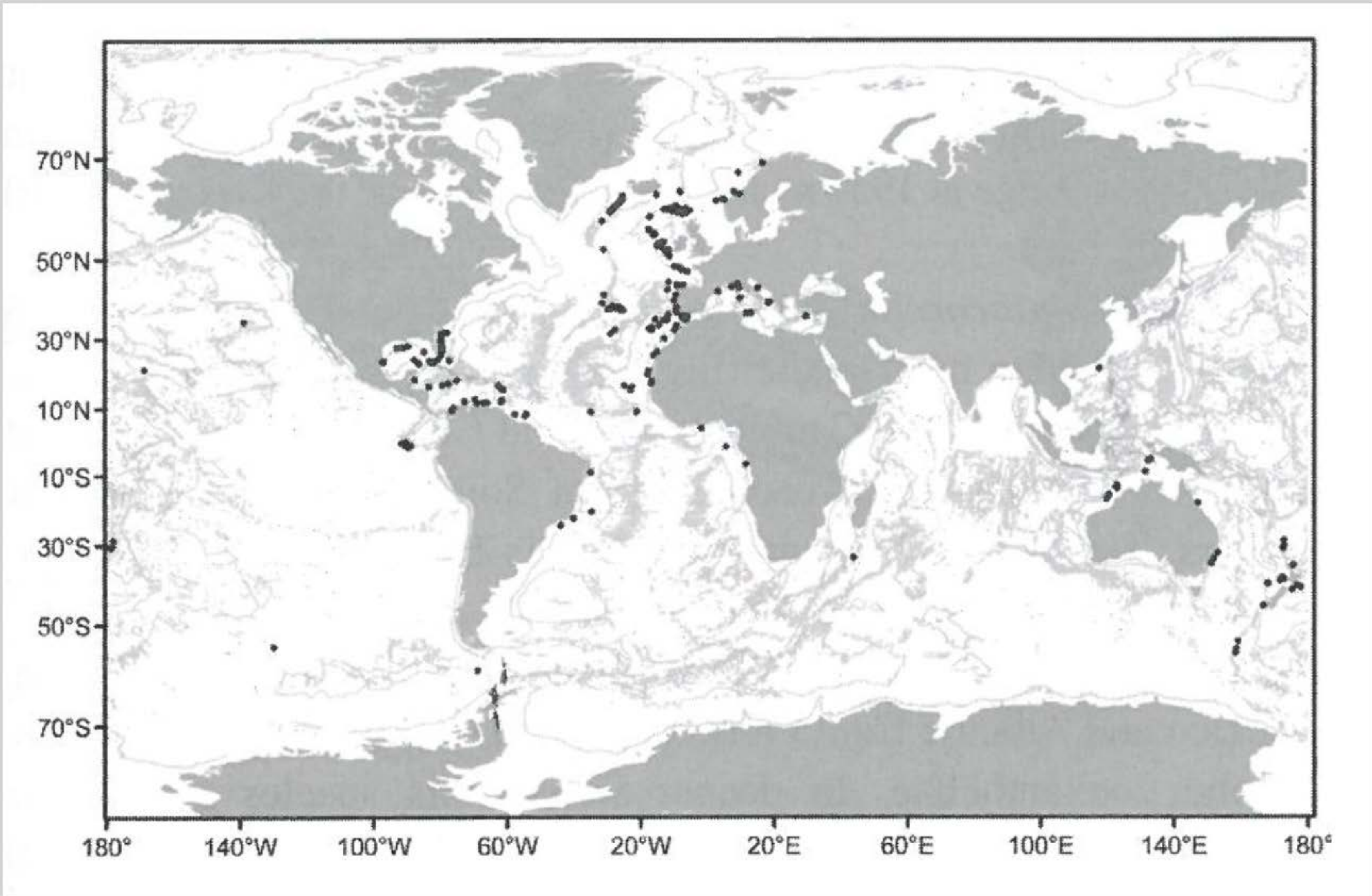


Figure A.5: Map showing the global distribution of Madrepora oculata (●) (from Roberts et al., 2009) (isobaths at 2,000 m, 5,000 m and 9,000 m).

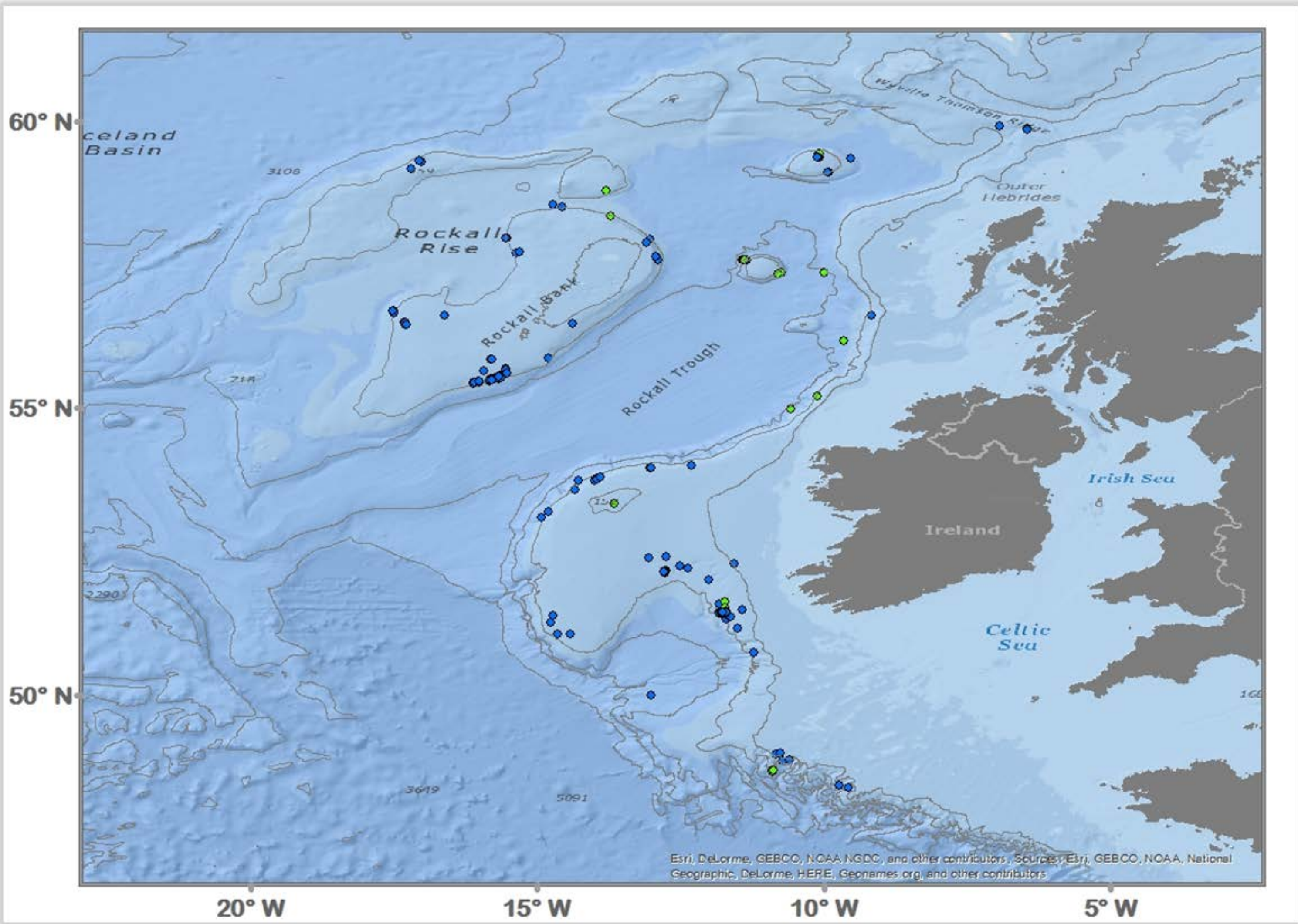


Figure A.6: Map showing the distribution of *Madrepora oculata* (●) and *Solenosmilia variabilis* (●) in Irish offshore waters based on direct observations recorded in published and online sources (see Project GIS Database). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

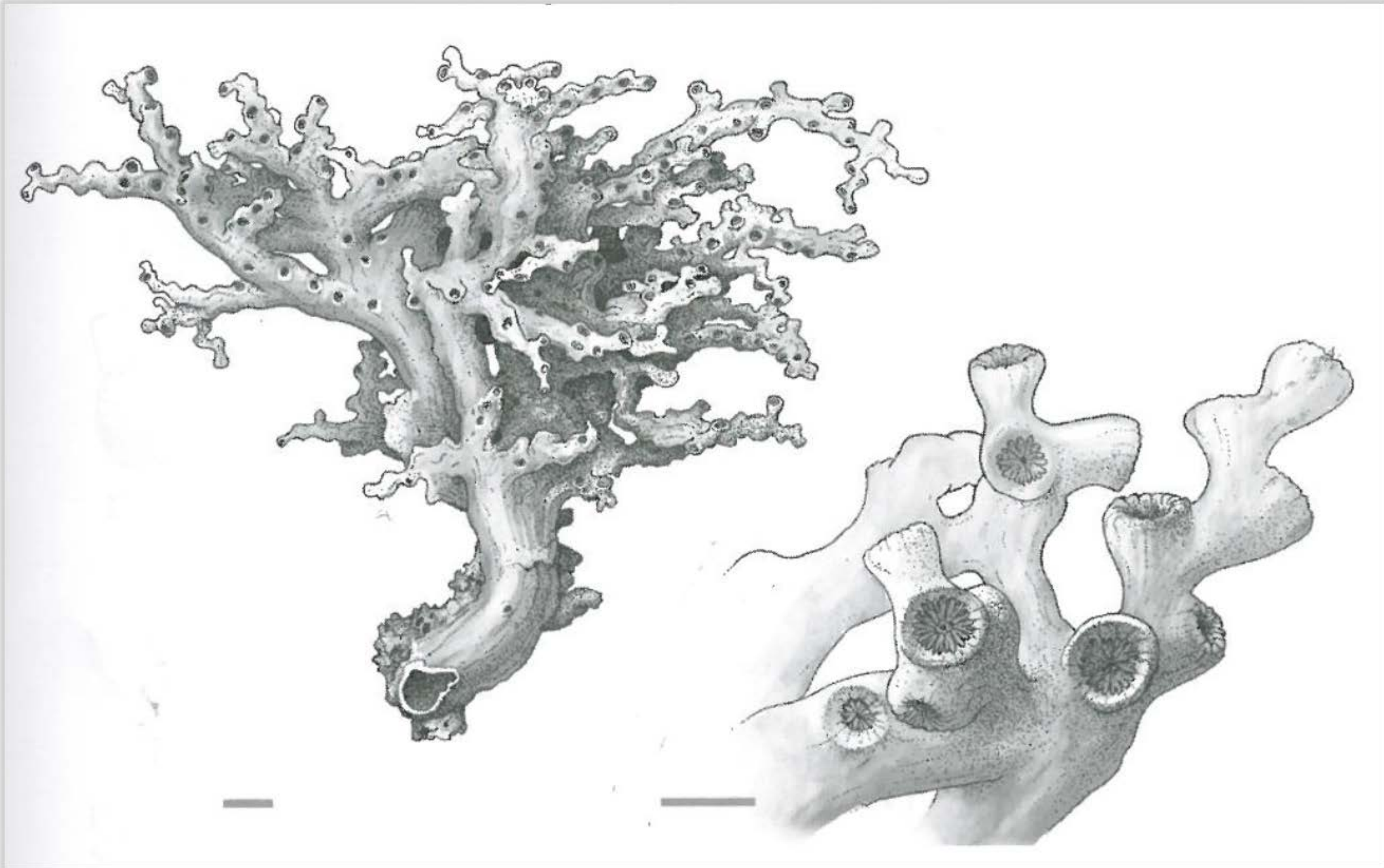


Figure A.7: Drawing of *Madrepora oculata* skeleton showing framework formed by the coral colony and details of individual polyp (from Roberts et al., 2009). Scale bars: 10 mm (colony) and 4 mm (polyp detail).

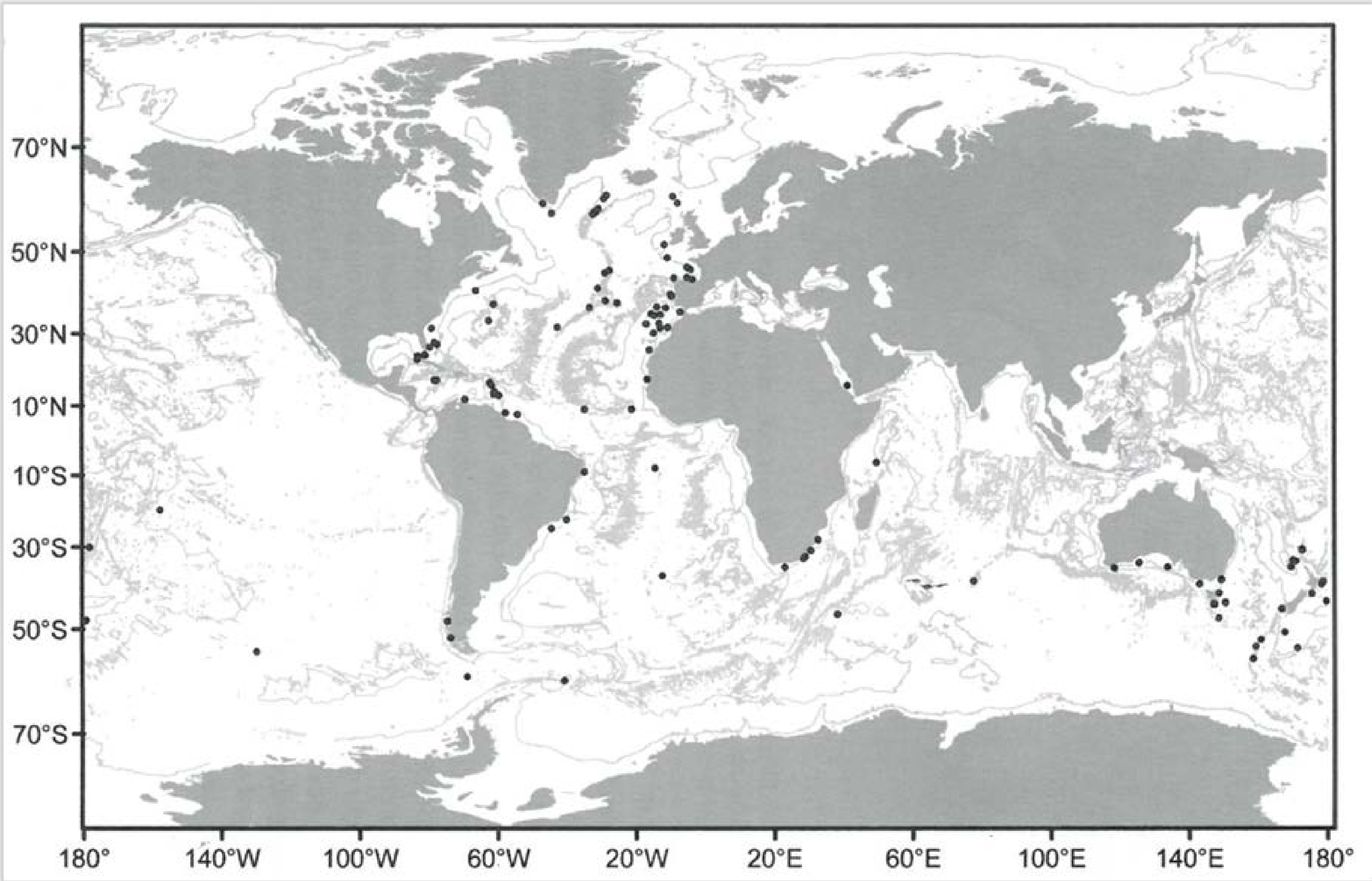


Figure A.8: Map showing the global distribution of *Solenosmilia variabilis* (●) (from Roberts et al., 2009) (isobaths at 2,000 m, 5,000 m and 9,000 m).

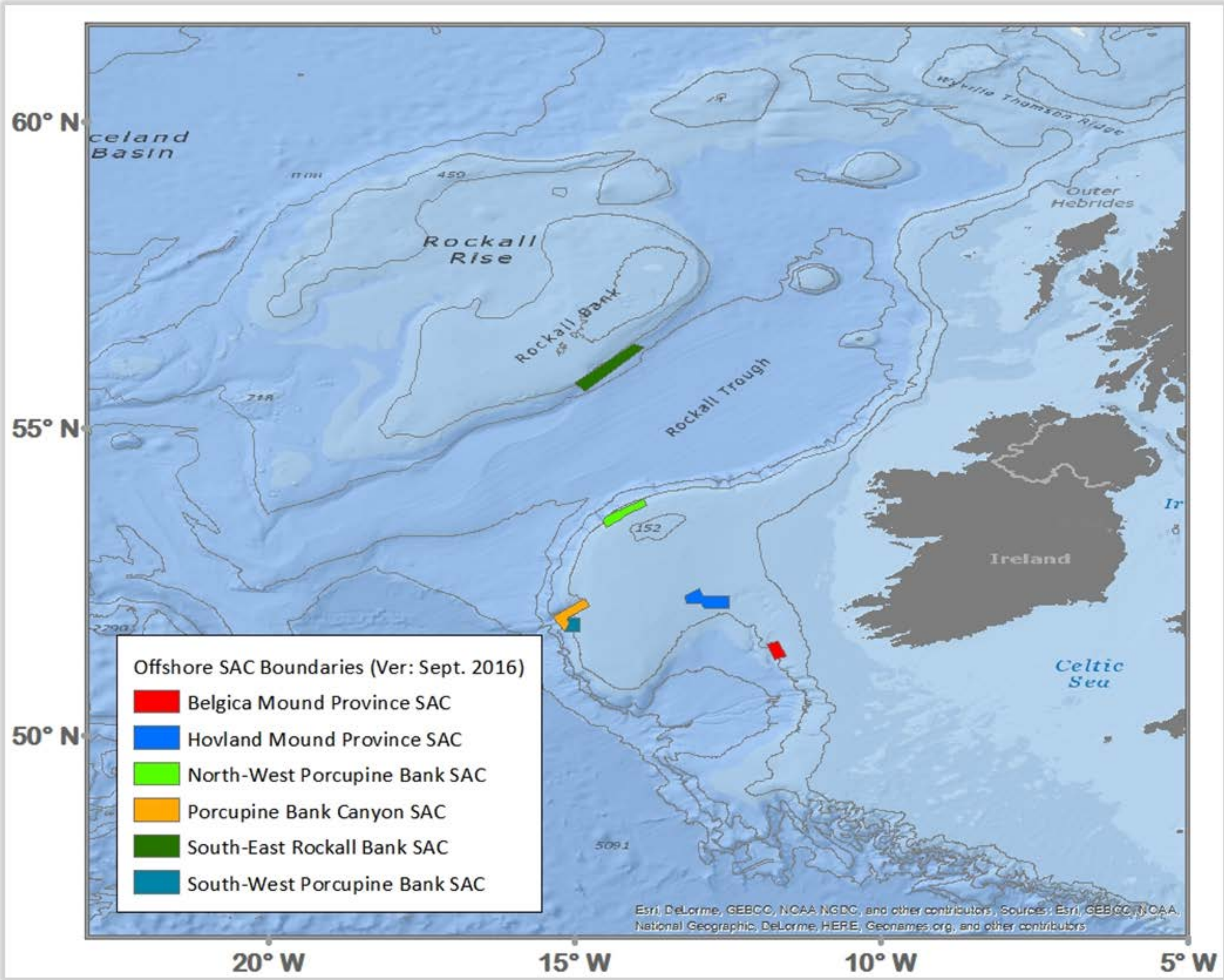


Figure A.9: Offshore Special Areas of Conservation in Irish offshore waters (see Project GIS Database). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

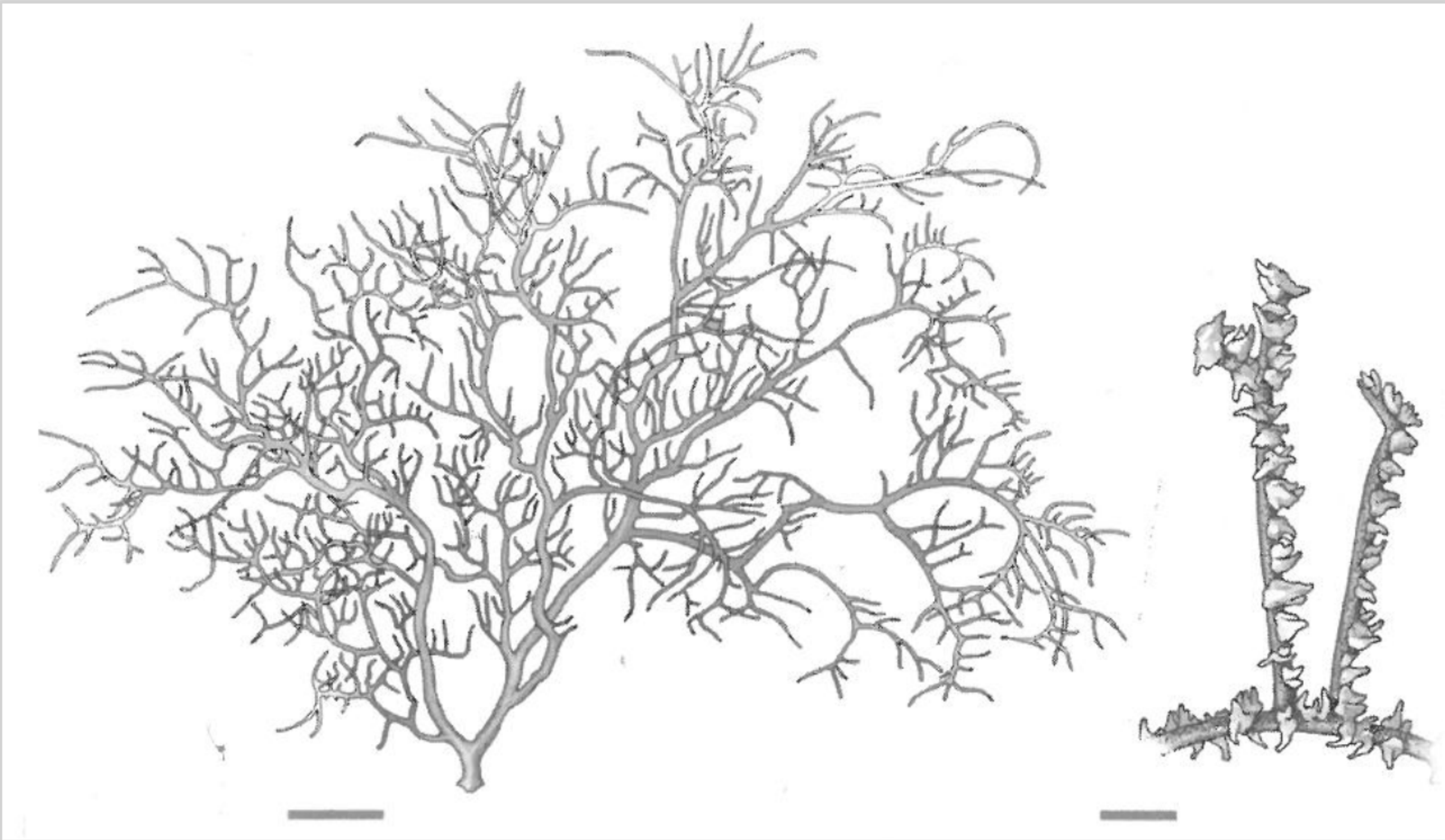


Figure A.10: Drawing of a colony of the Antipatharia coral species *Leiopathes sp*. showing framework formed by the coral colony and details of individual polyps (from Roberts et al., 2009). Scale bars: 50 mm (colony) and 3 mm (polyps detail).

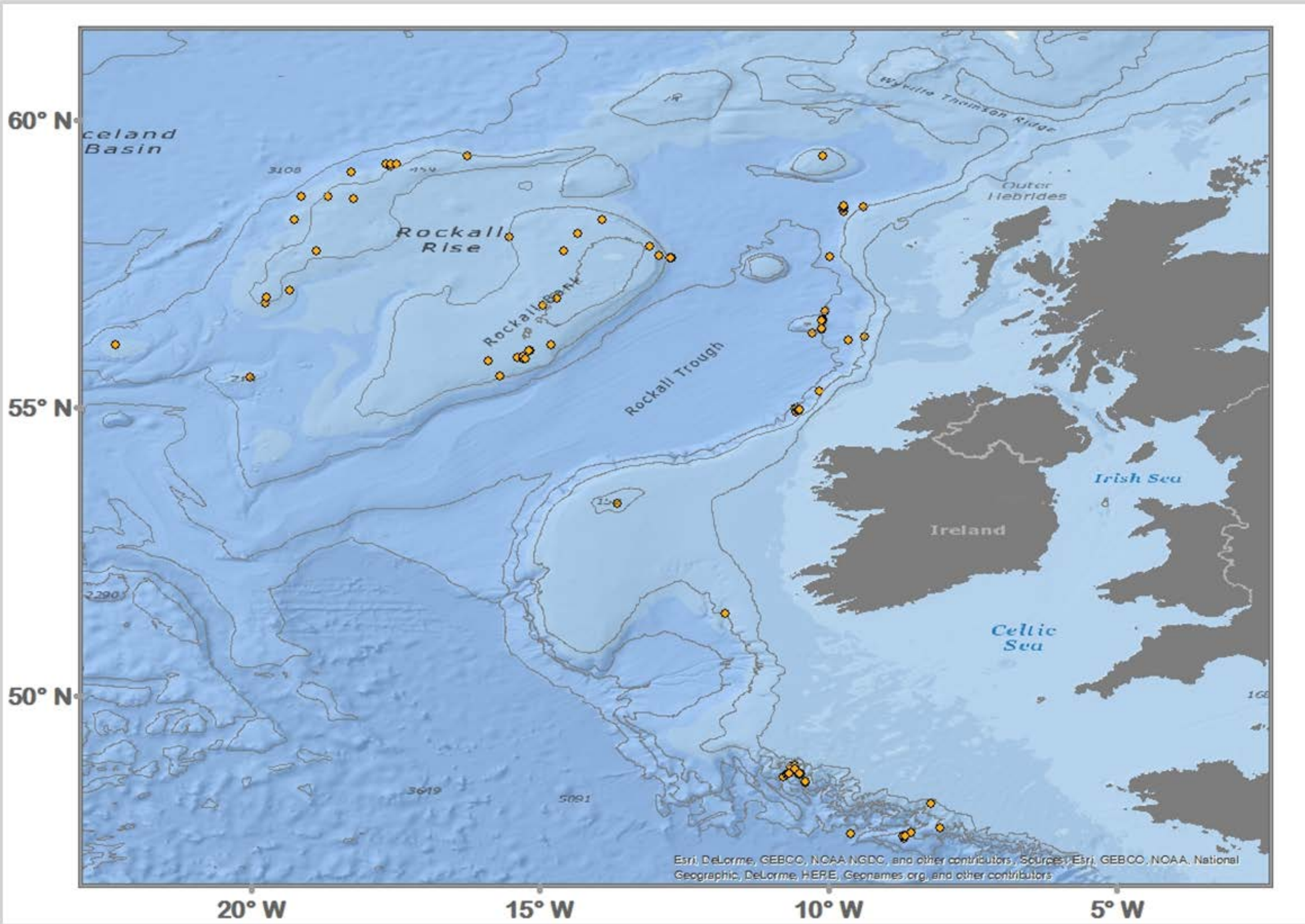


Figure A.11: Map showing the distribution of Antipatharia (black corals) (●) in Irish offshore waters based on direct recorded in published and online sources (see Project GIS Database). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

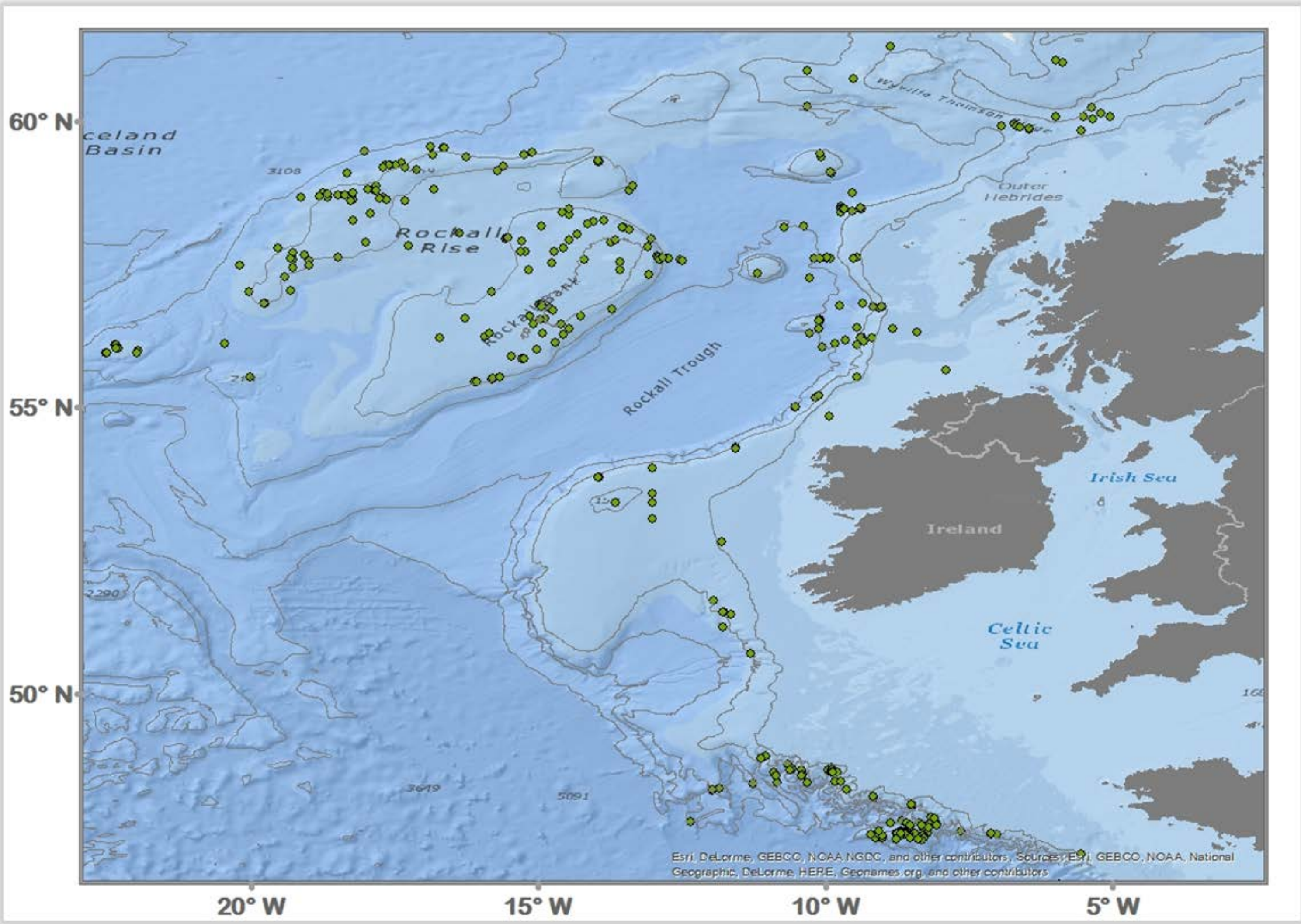


Figure A.12: Map showing the distribution of Octocorallia (soft corals) (●) in Irish offshore waters based on observations recorded in published and online sources (see Project GIS Database). The Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m bathymetry contours are shown.

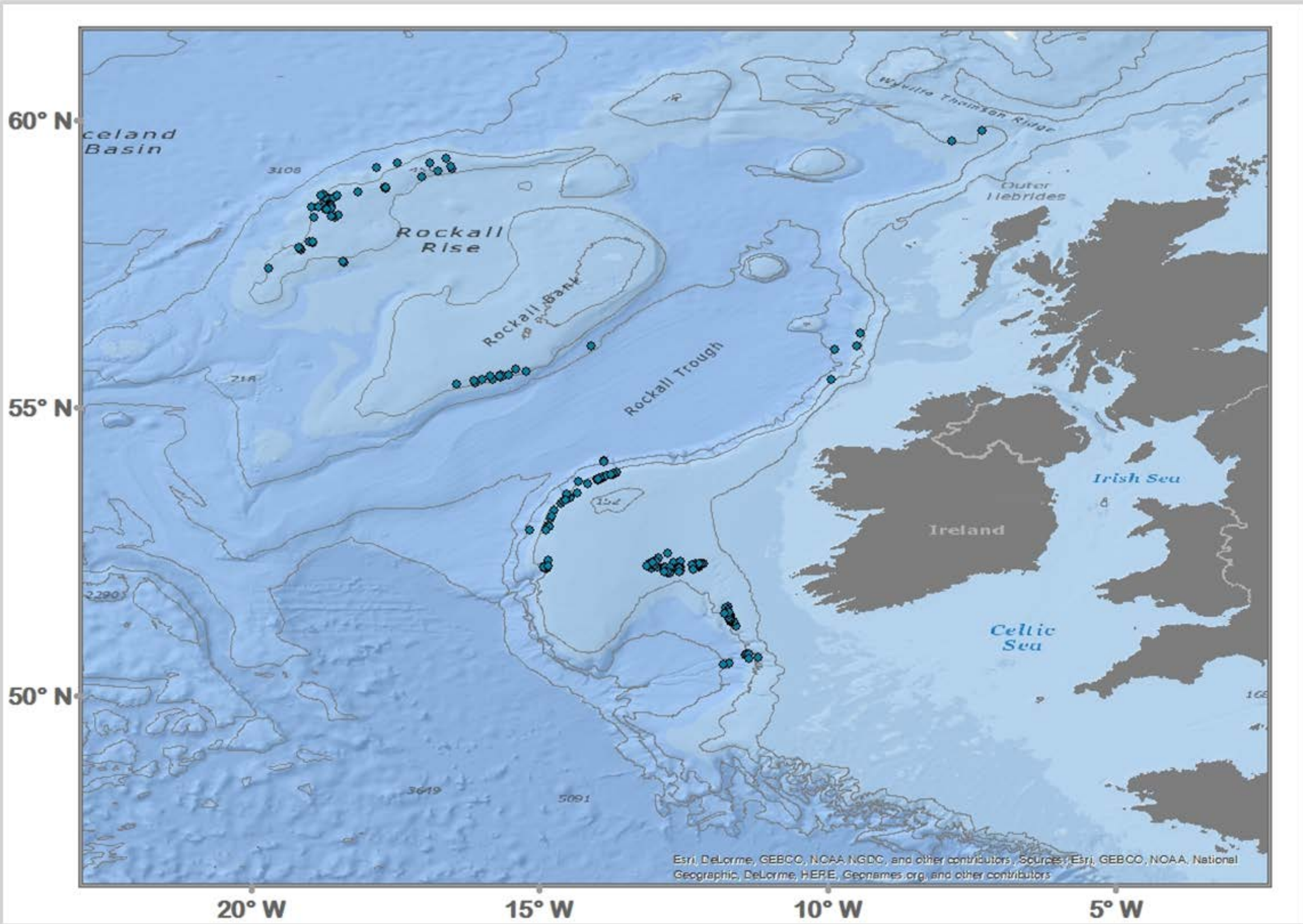


Figure A.13: Map showing the distribution of Carbonate Mounds (●) in Irish offshore waters based on observations recorded in published and online sources (see Project GIS Database). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

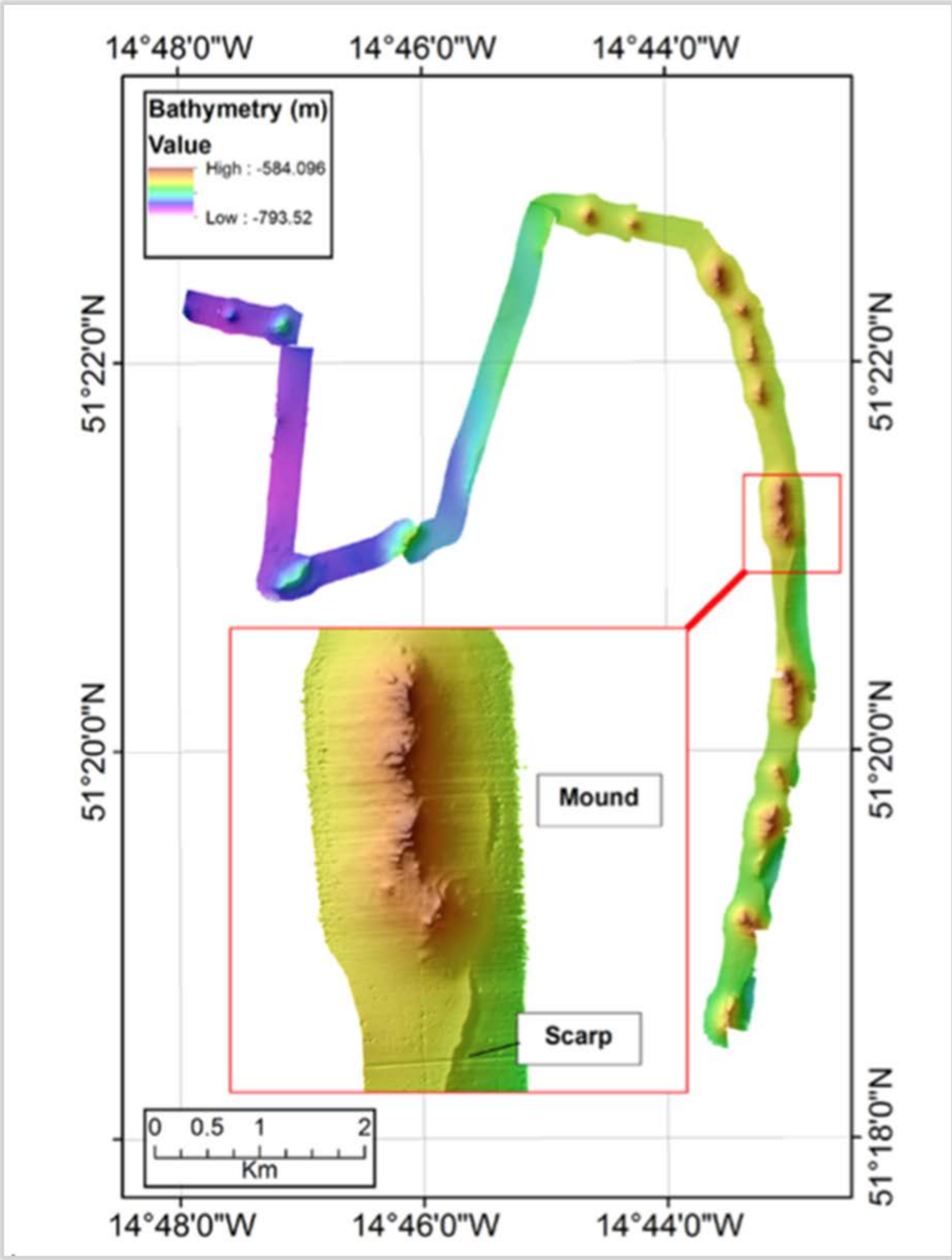


Figure A.14: Multibeam bathymetry showing carbonate mounds and associated scarp features (from Stapleton et al., 2013).

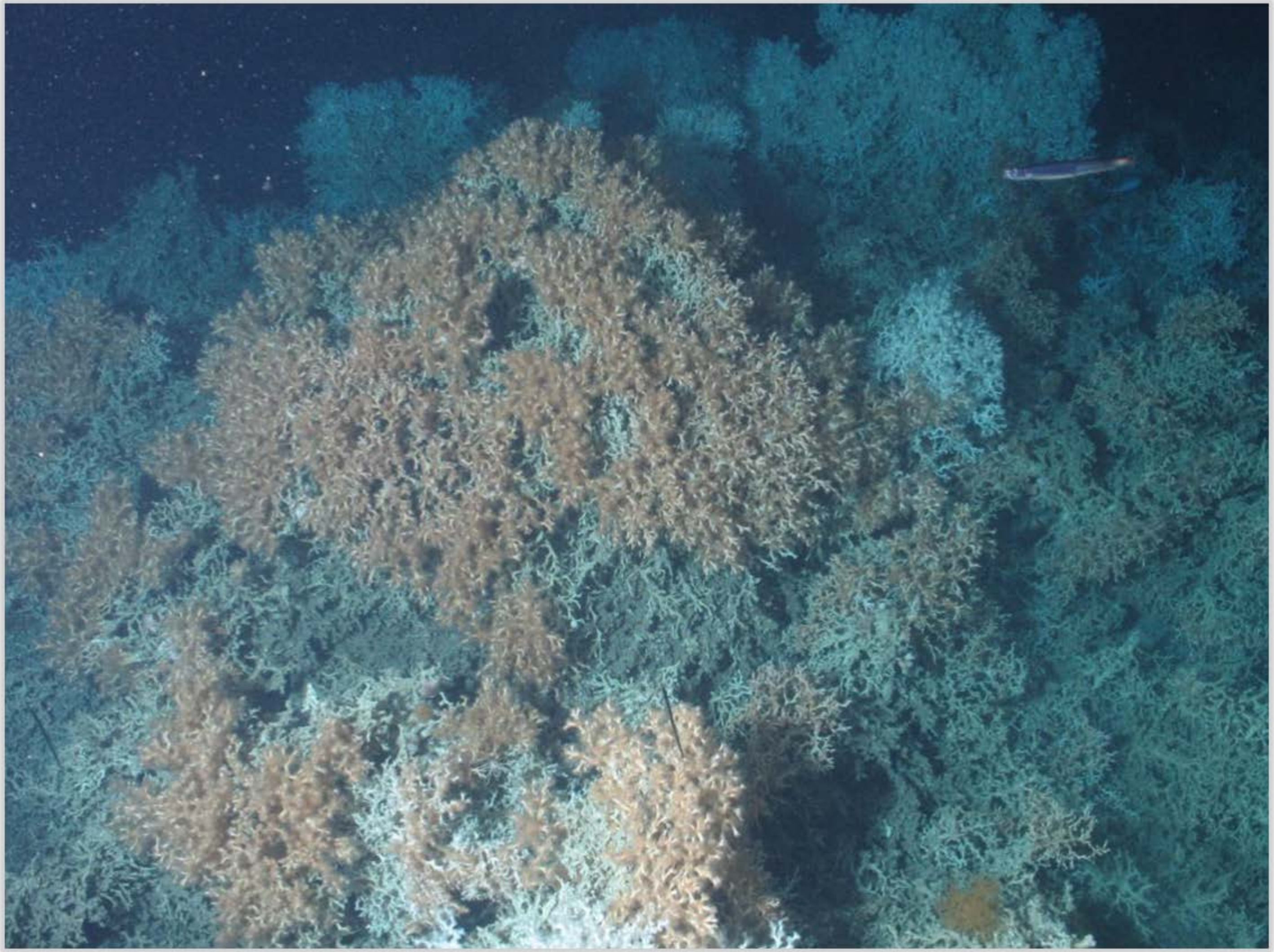


Figure A.15: Coral mounds in the Arc Province supporting *Lophelia pertusa* reefs (from Stapleton et al., 2013).

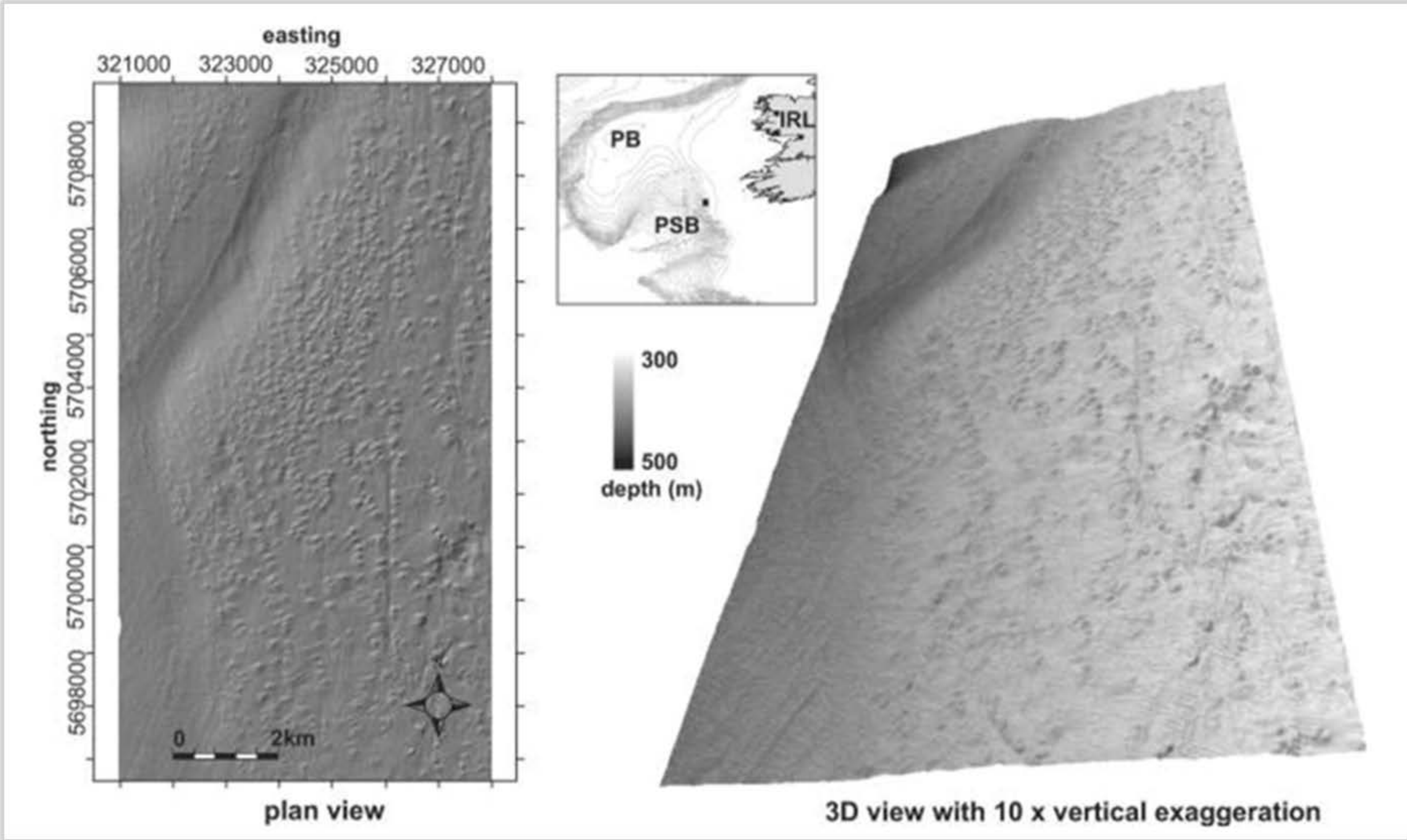


Figure A.16: The Macnas Mounds in the Porcupine Seabight (from Wilson et al., 2007)

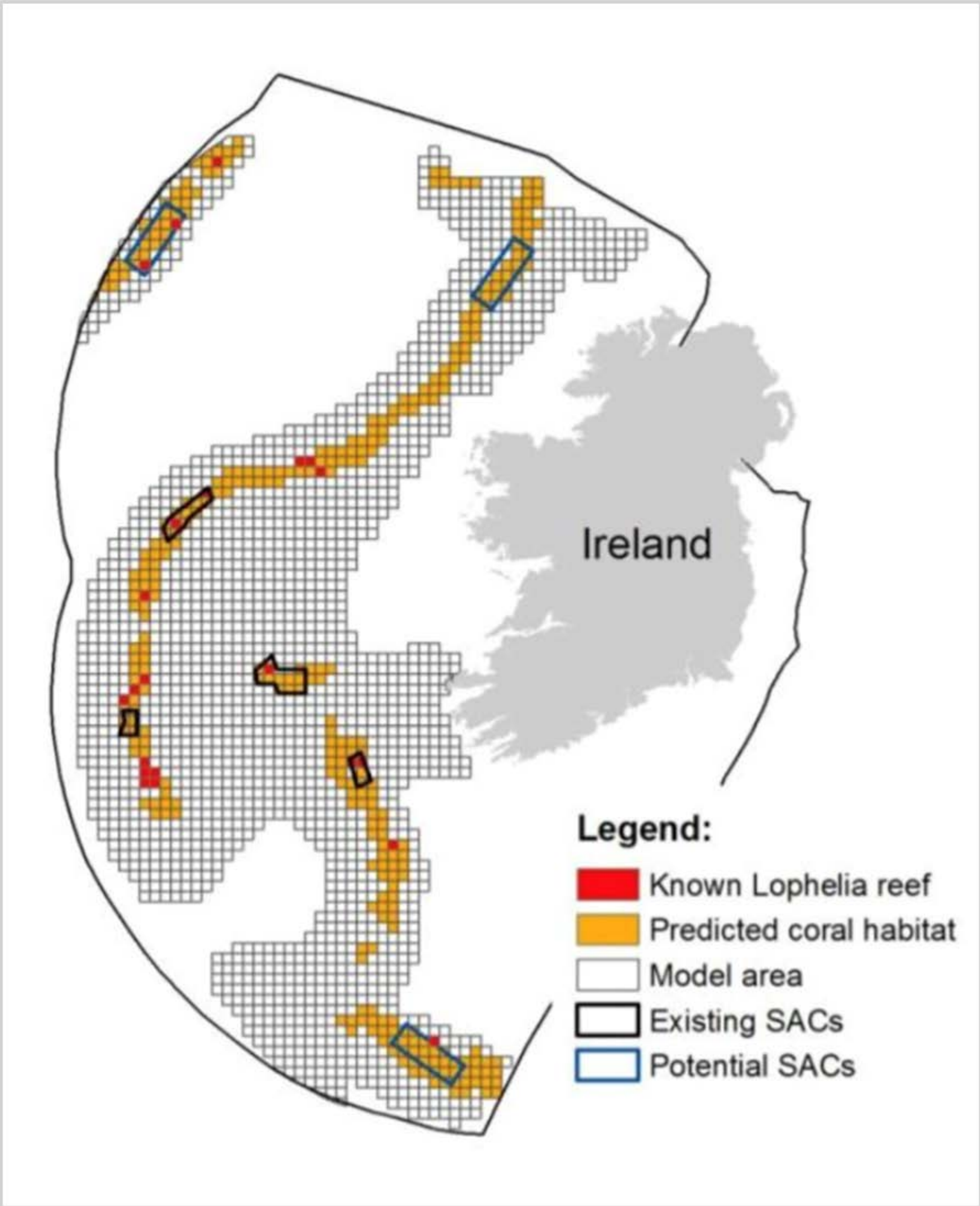


Figure A.17: Habitat suitability map for *Lophelia pertusa* for Irish offshore waters. Map showing the distribution of known and predicted *Lophelia pertusa* reef habitat, as well as existing and suggested (potential) coral SACs within the Irish Exclusive Fisheries Zone (solid black line). Each grid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

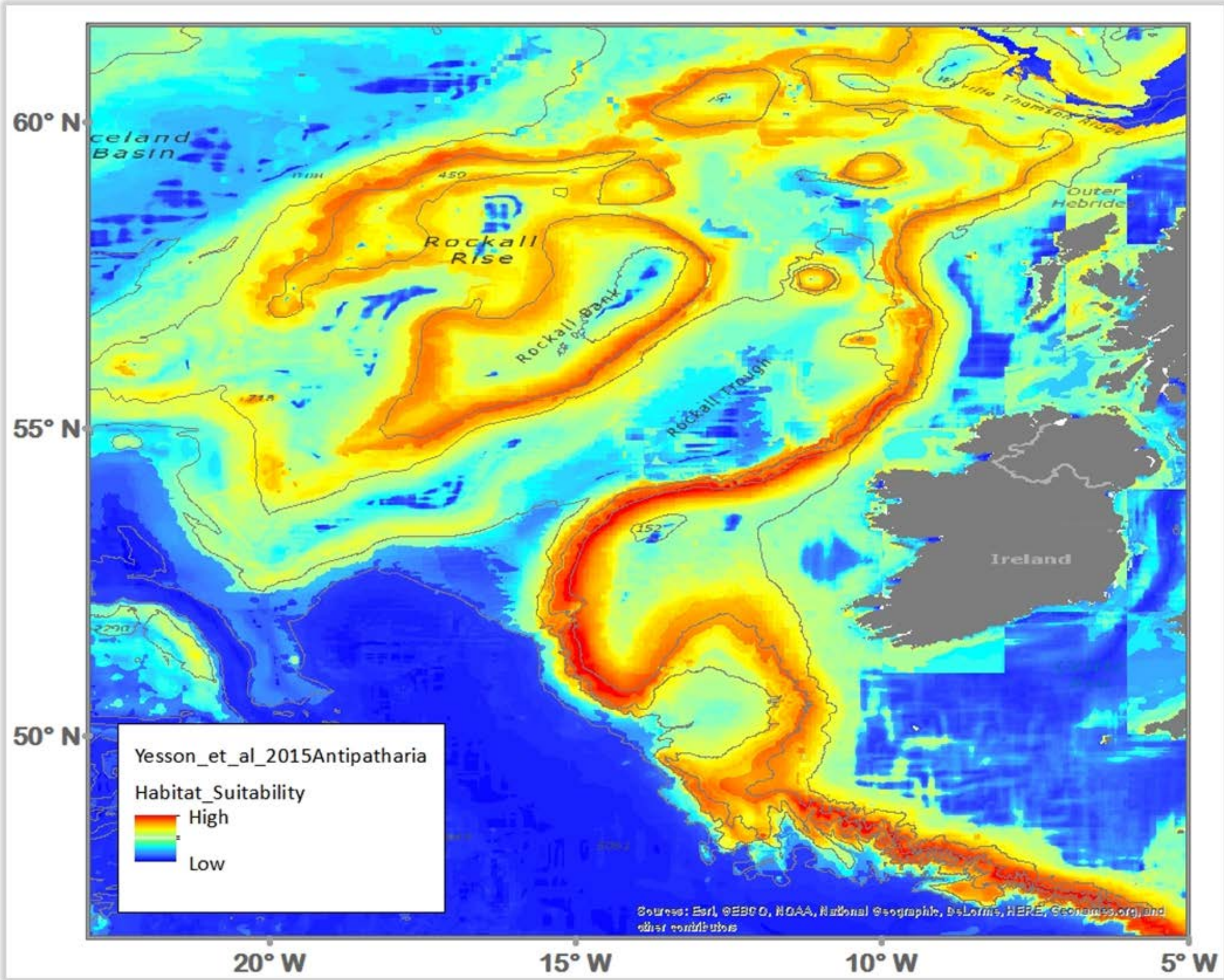


Figure A.18: Habitat suitability map for Anthipatharia taxa in the Irish offshore waters (from Yesson et al., 2015) (see Project GIS Database). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

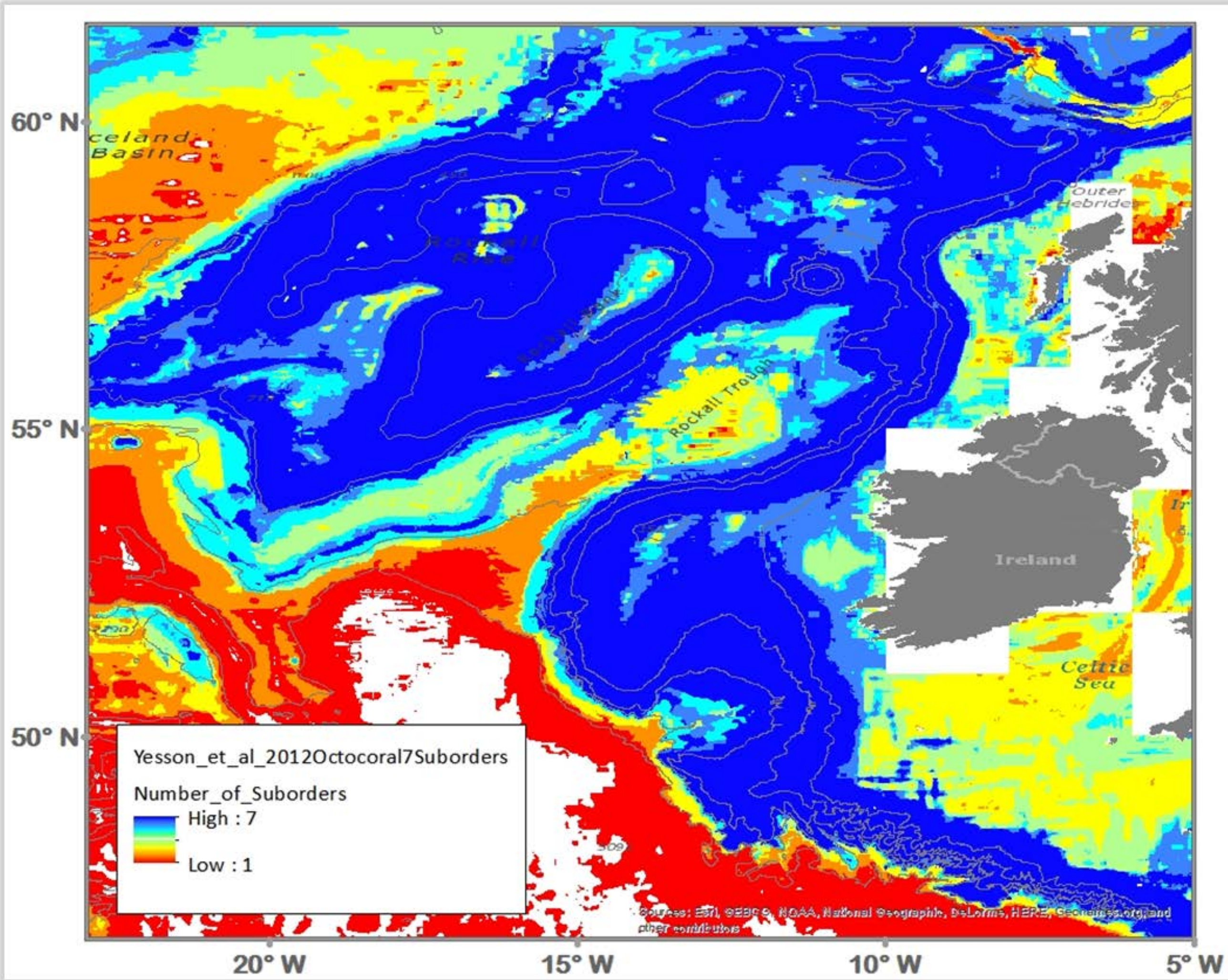


Figure A.19: Habitat suitability map for seven Octocorallia sub-order taxa in the Irish offshore (from Yesson et al., 2012) (see Project GIS Database). Isobaths at 200 m, 1,000 m, 2,000 m, 3,000 m and 4,000 m.

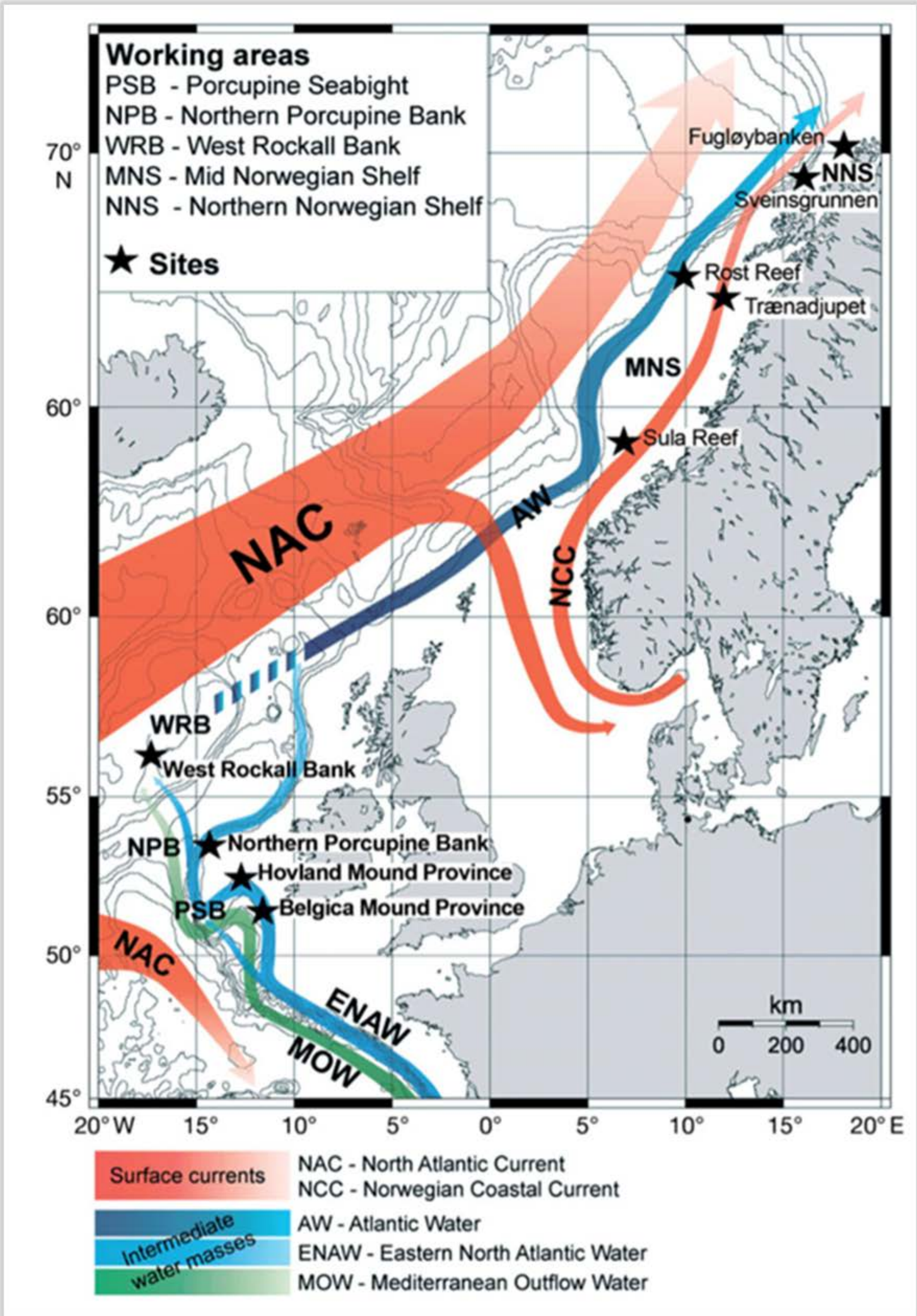


Figure A.20: Investigated locations of cold-water reefs along the Celtic and Norwegian Margin and prevailing current regimes (from Dullo et al., 2008). Red arrows indicate surface currents of the North Atlantic Current (NAC) and the Norwegian Coastal Current (NCC), blue and green arrows indicate intermediate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

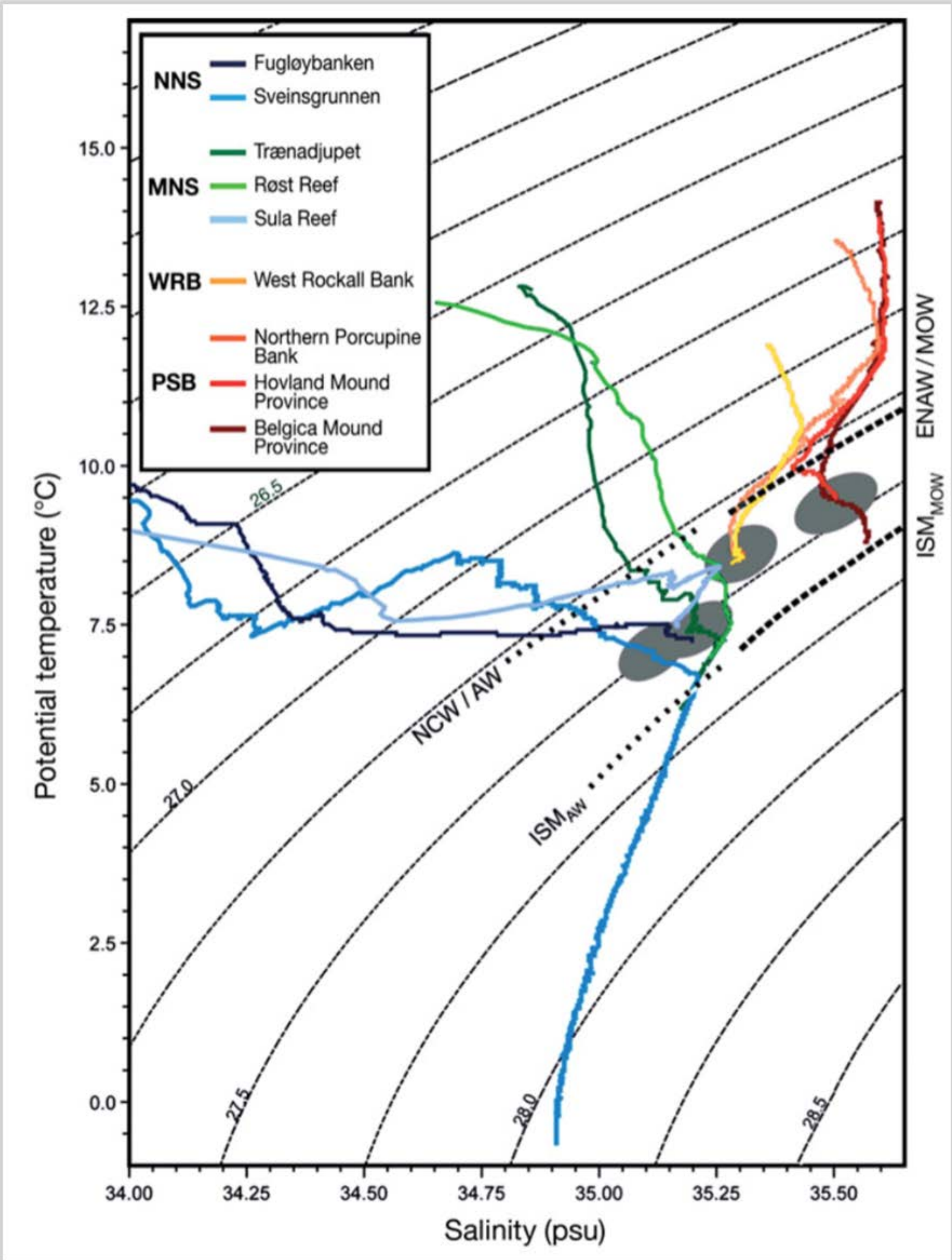


Figure A.21: Temperature – Salinity plot of known coral sites in Dullo et al. (2008). Thin dashed lines indicate levels of iso-density (δΔ) in kg/ m3. Grey patches show habitats of living cold-water coral reefs. The lower limit is confined by the Intermediate Salinity Maximum (Hernández-Kantún et al., 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.

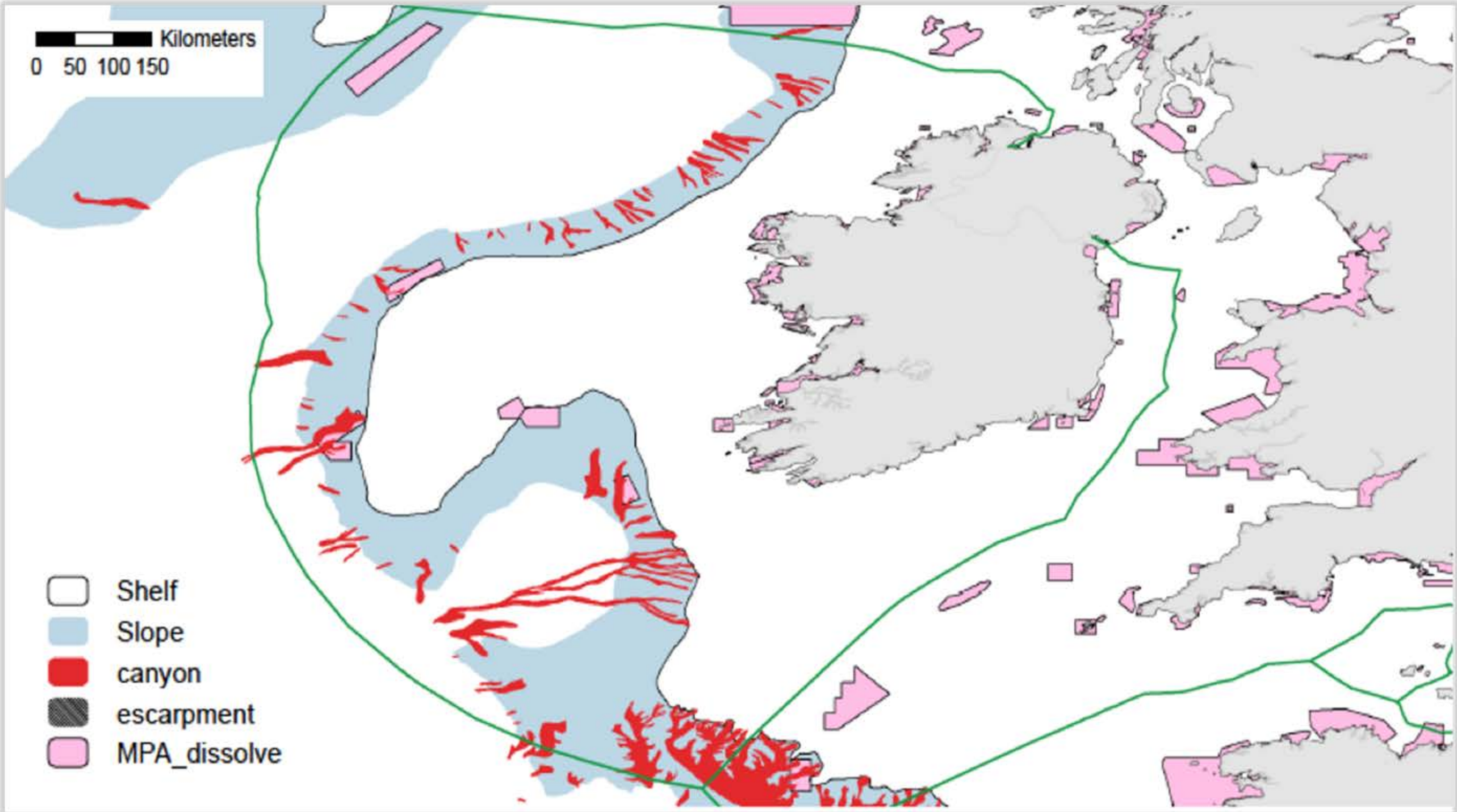


Figure A.22: Quantification of Irish seafloor geomorphic features (from Harris et al., 2014). The location and extent of current marine protected areas is also shown.

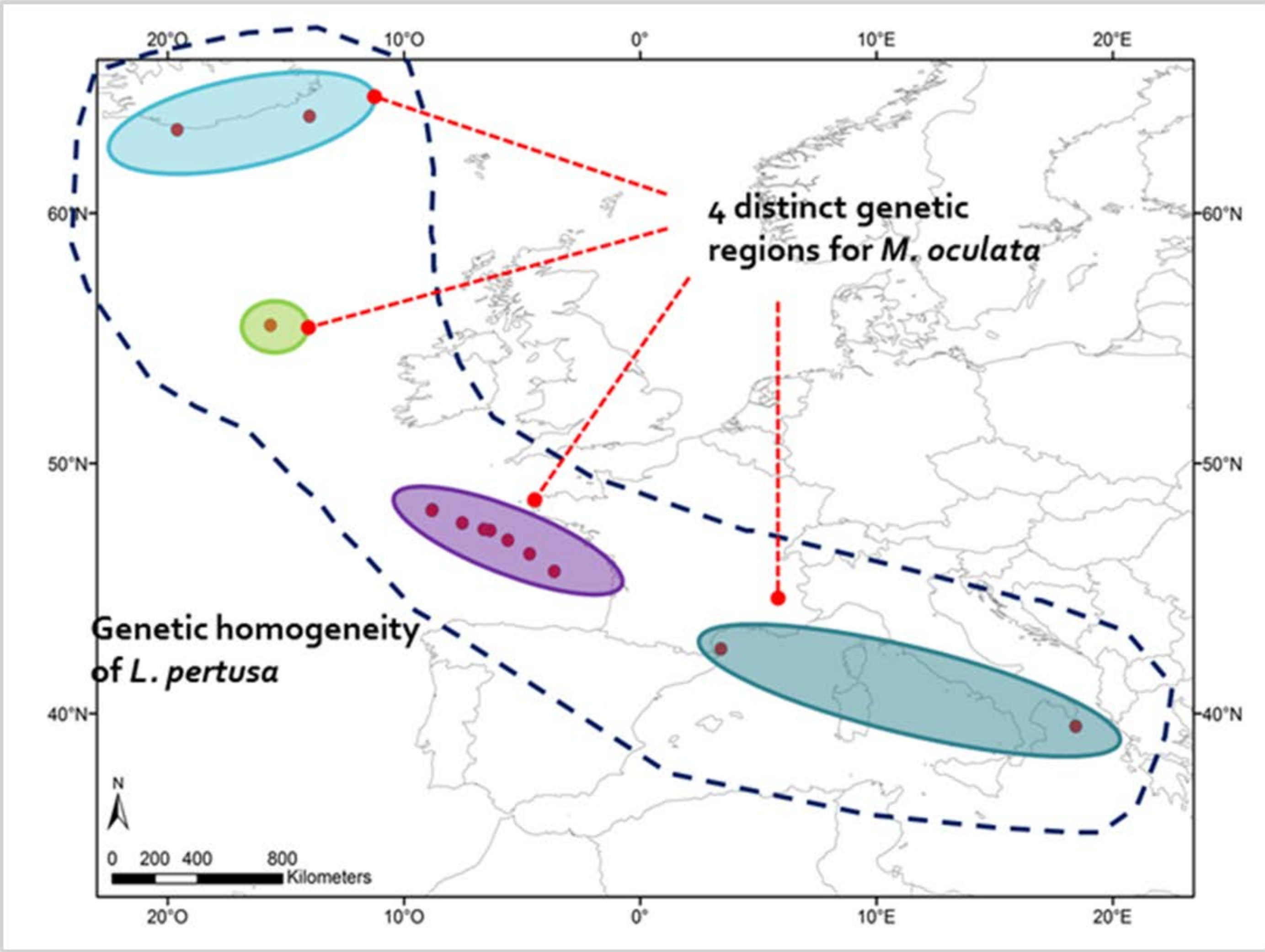


Figure A.23: Map illustrating the genetic connectivity, highlighting genetically distinct areas (colour patches) for *Madrepora oculata* and the rather homogeneous distribution of apparently highly connected populations of *Lophelia pertusa* (dots) (from CoralFISH, 2013.

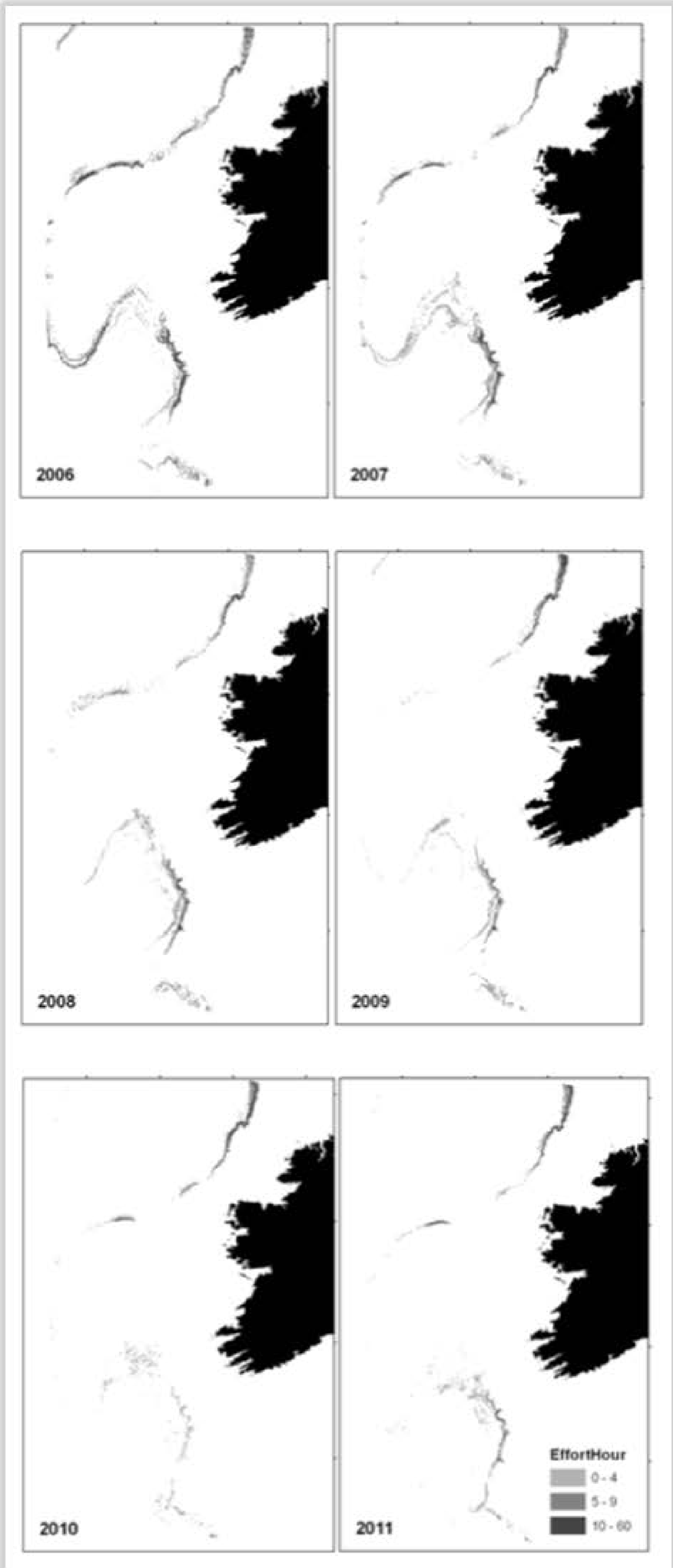


Figure A.24: Spatial positions of French and Irish deep-water fishing effort by vessel monitoring system data as the annual sum of hours within each grid cell between 800 m and 2000 m for the years 2006 to 2011. Contour lines in light grey present the 800 m and 2000 m depth bands. For definition of 'deep-water' effort see Dransfeld et al. (2013).

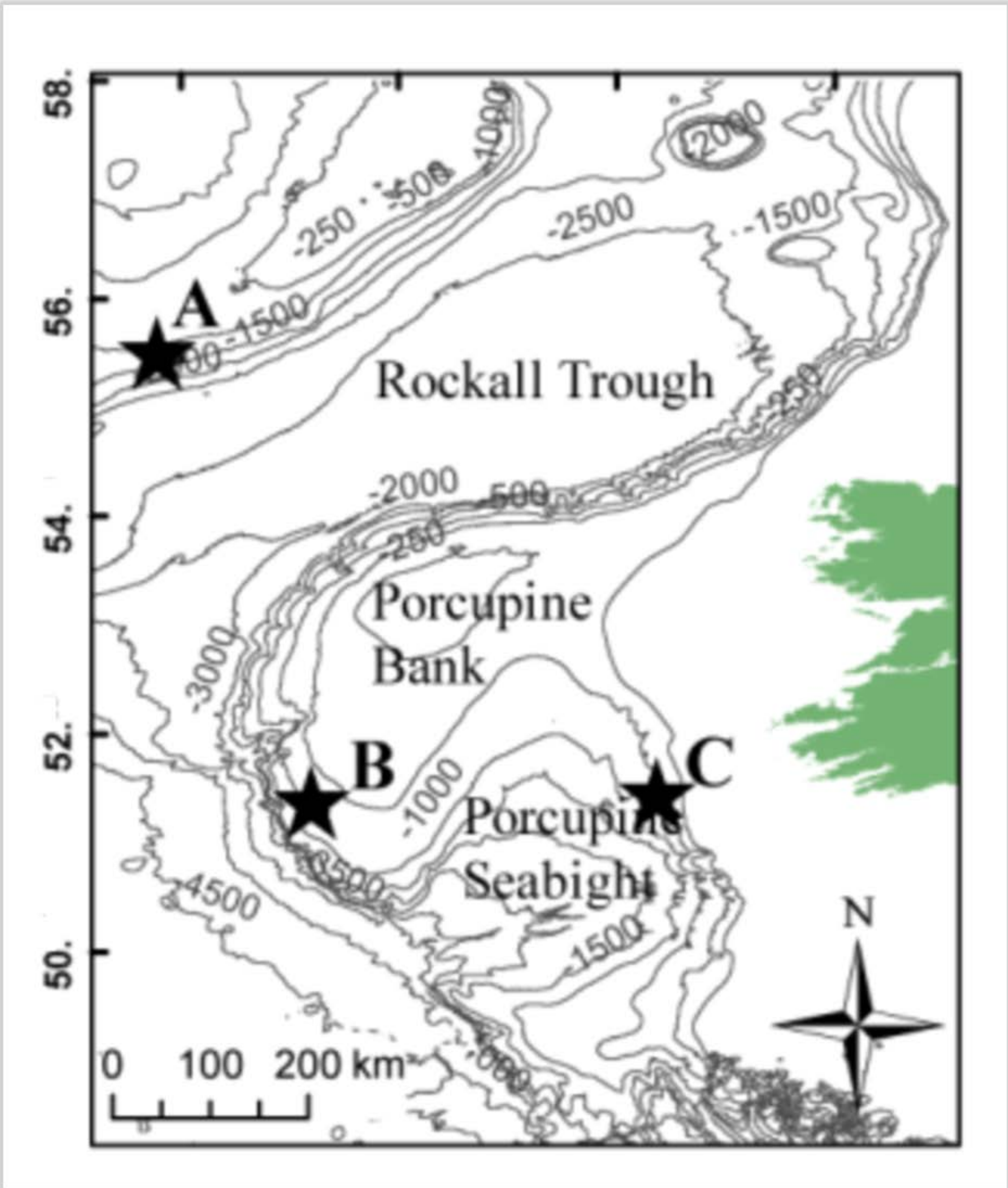


Figure A.25: Map illustrating sampling locations at A, Logachev Mounds; B, Arc Mounds and C, Belgica Mounds (from CoralFISH, 2013).

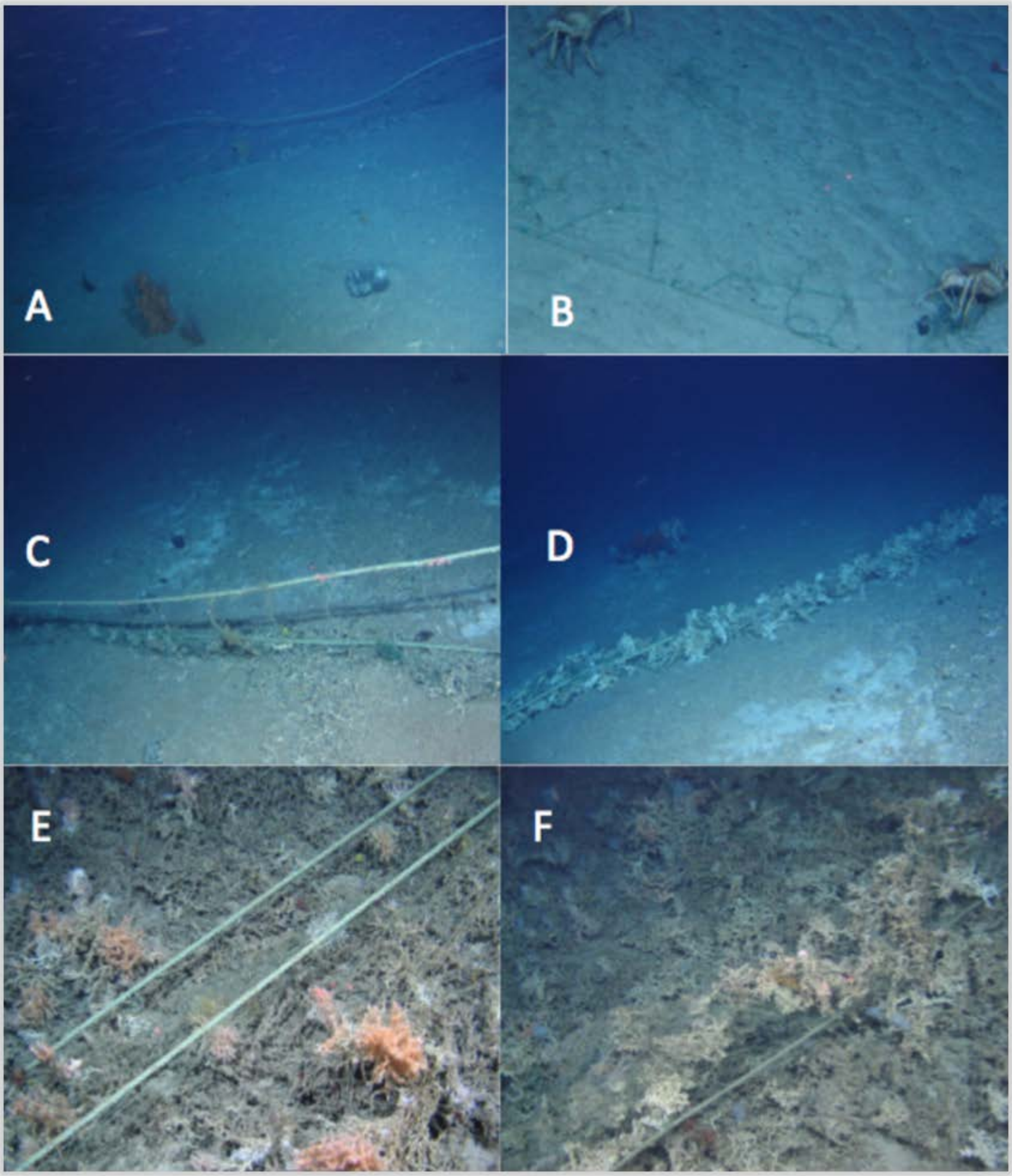


Figure A.26: Examples of lost fishing gear, suspected trawl tracks and items of rubbish at carbonate mound habitats (from EC CoralFISH project).

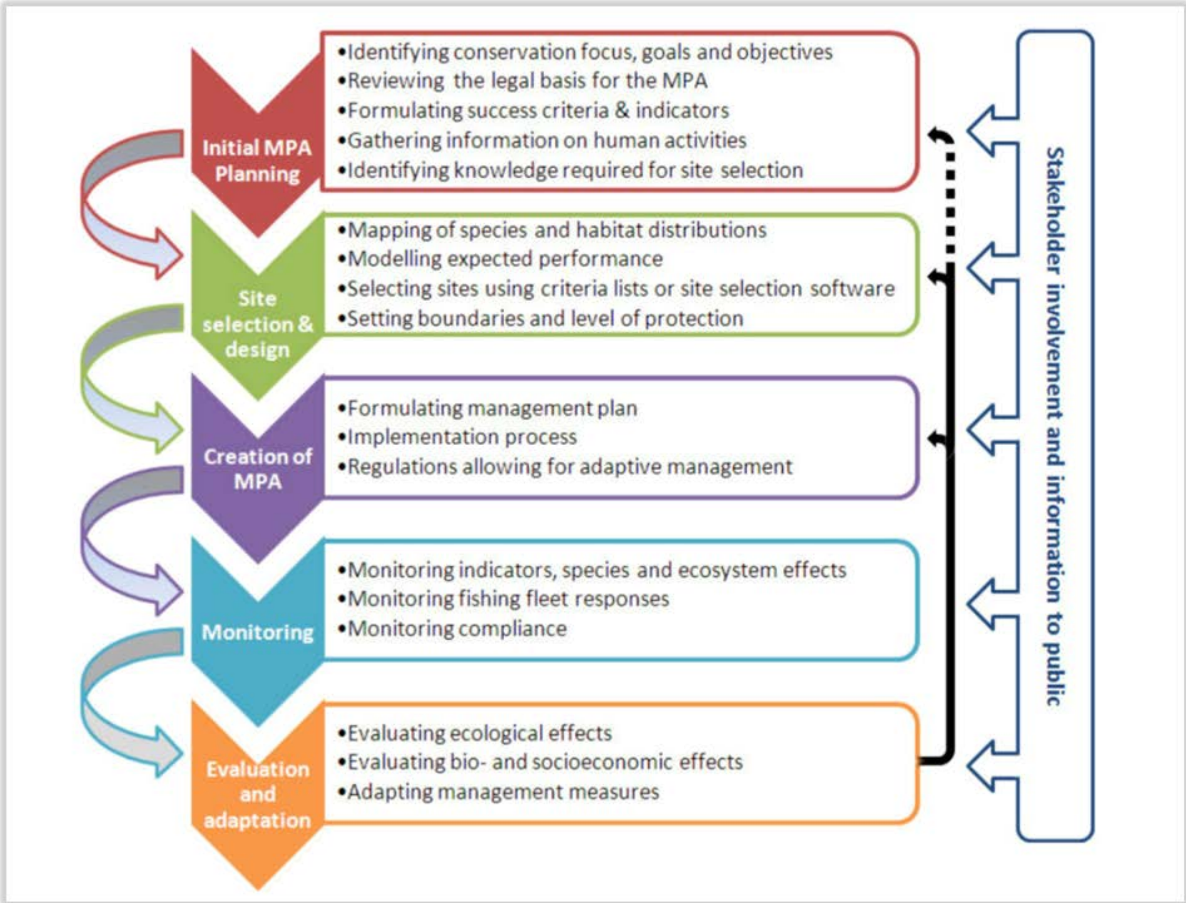


Figure A.27: The PROTECT planning framework for developing and managing marine protected area (from PROTECT, 2009).

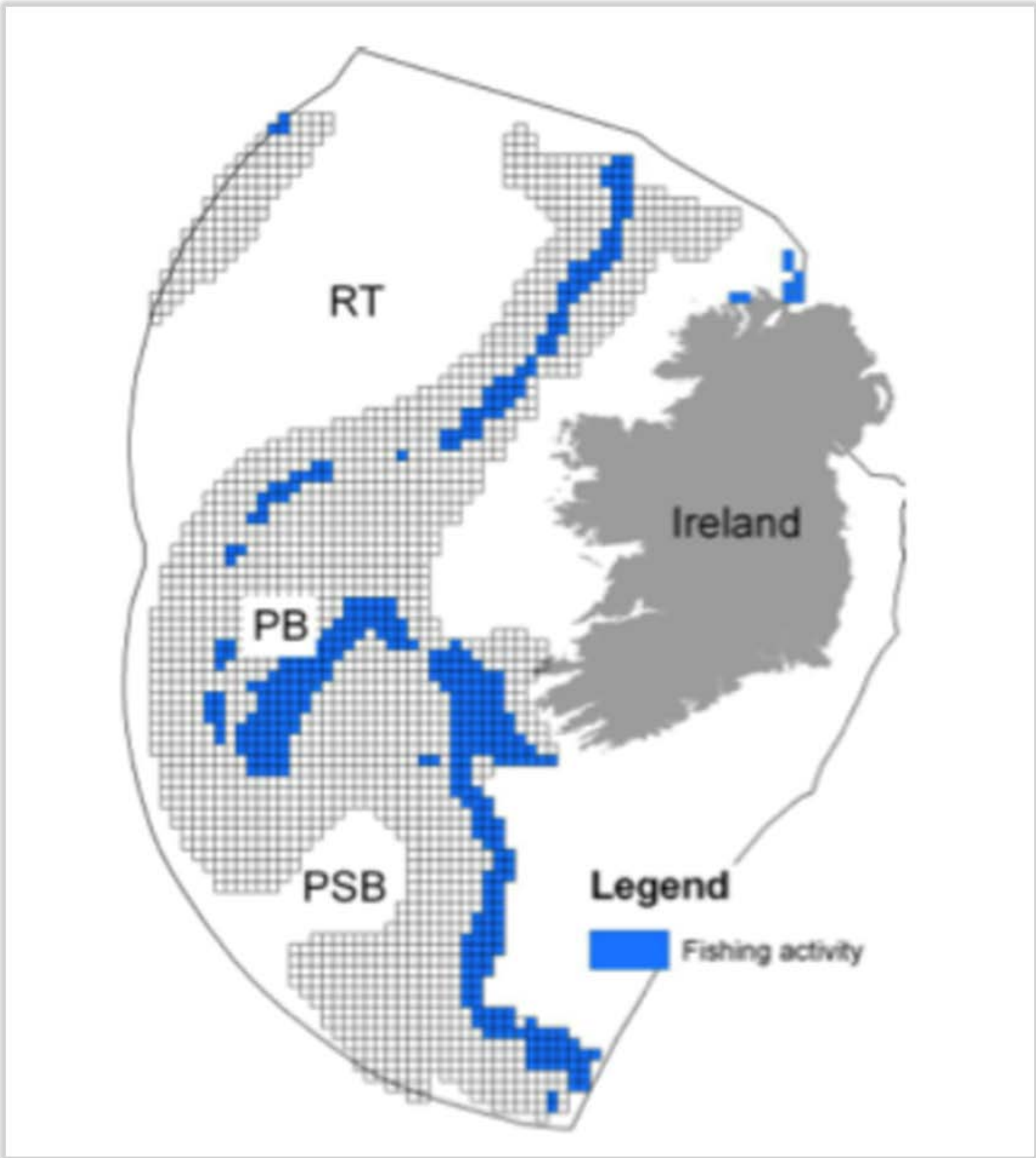


Figure A.28: The distribution of fishing activity off the Irish west coast derived from analysis of VMS records from the British fishing fleet (CoralFISH, 2013).

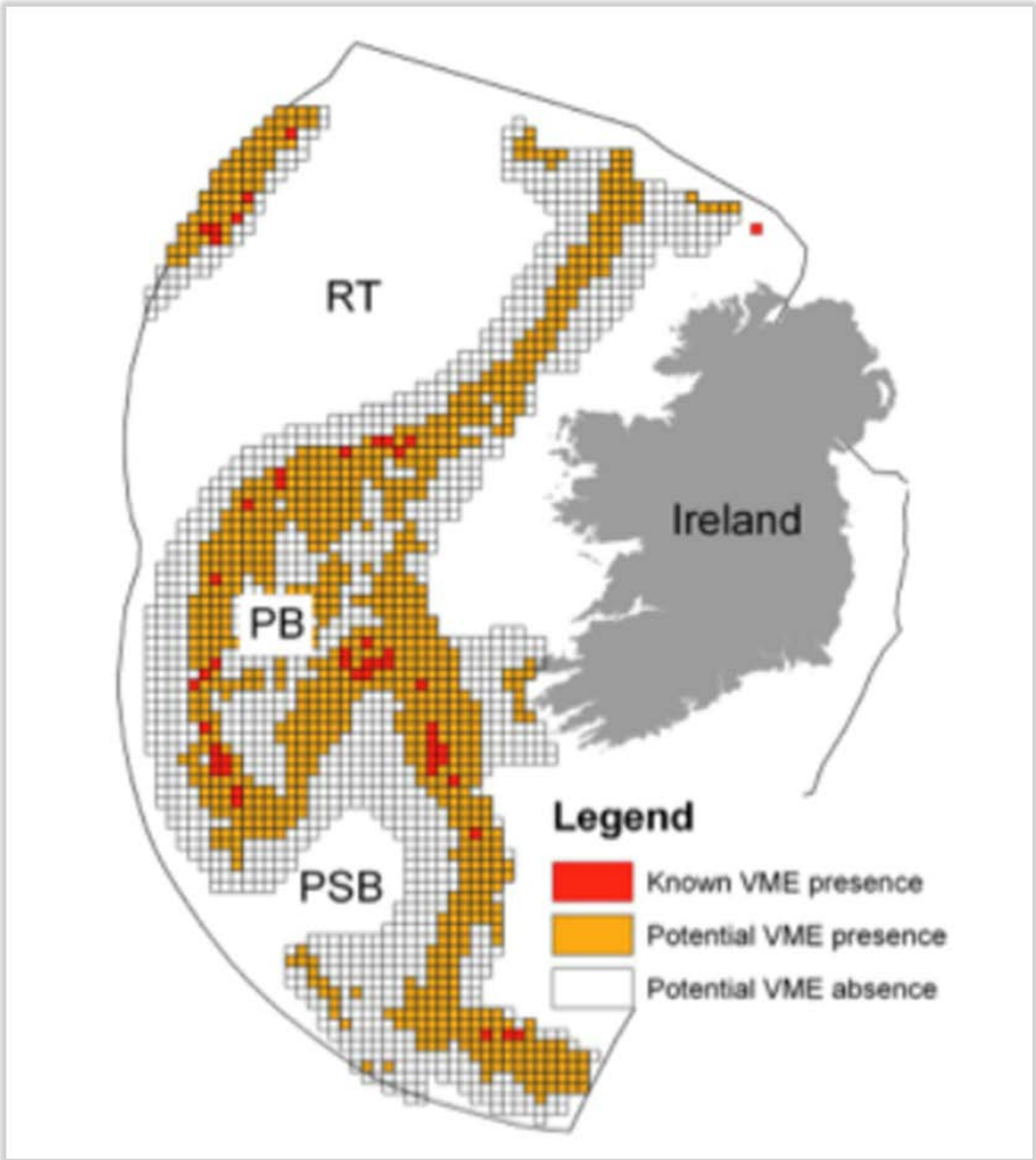


Figure A.29: The known, predicted presence and absence of vulnerable marine ecosystems (VME) (cold-water coral reefs) in Irish waters mapped onto a 10 x 10km grid. Predicted coral reef distribution is based on the output from the NUIG high resolution coral reef habitat suitability model (Rengstorf et al., 2013; CoralFISH, 2013).

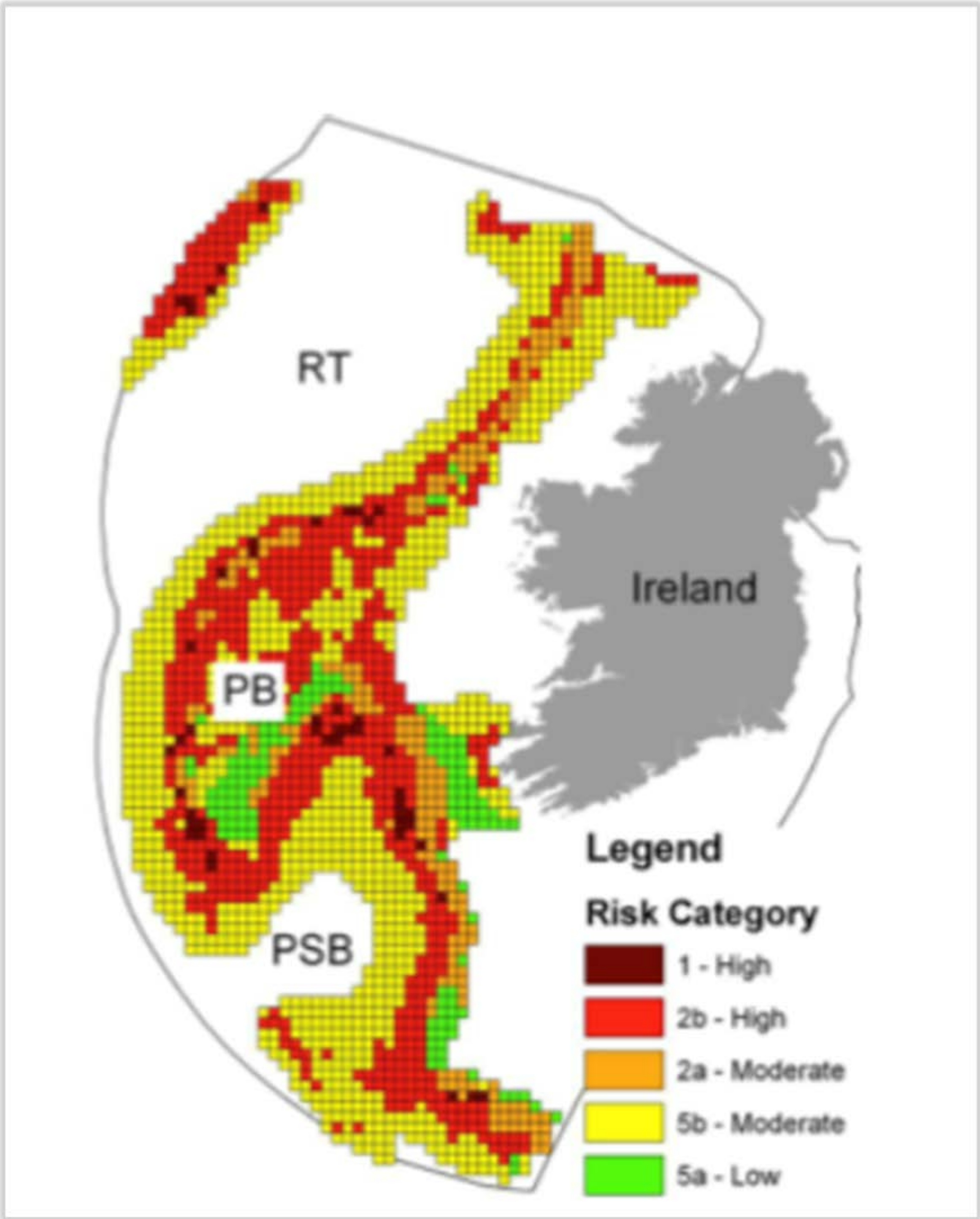


Figure A.30: Map showing assigned risk category (from CoralFISH, 2013).

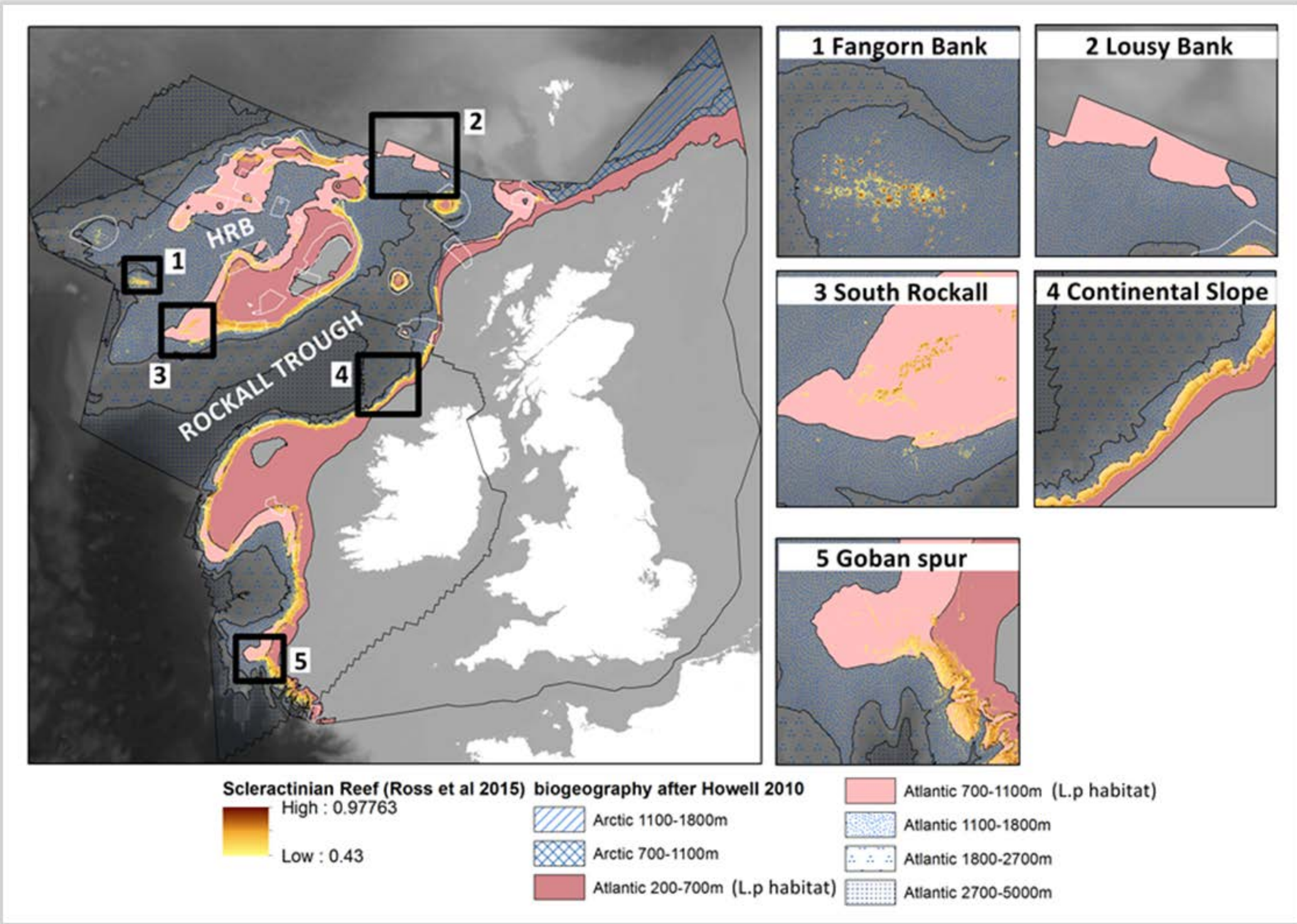


Figure A.31: Habitat suitable for *Lophelia pertusa* species and Scleractinian reef (from Ross et al., 2015): *Lophelia pertusa* reef < 1,100m, *Solenosmilia variabilis* reef > 1,100 m), biogeography after Howell (2010). Also shows the maximum area currently protected and helps to identify areas where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

Appendix B - Faunal List for Reef Habitats in Irish Waters

Table B.1: 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 al., 2011; c, Robert et al., 2014; d, Johnson et al., 2013; e, Guilloux et al., 2010.

Taxon	Sessile	Mobile	Source
Phylum Cnidaria			
Class Anthozoa			
Subclass Hexacorallia			
Order Scleractinia			
Caryophyllia sp.	✓		b
Dendrophyllia sp.	✓		
Desmophyllum dianthus	✓		d
Desmophyllum pertusum	✓		b, c
Enallopsammia profunda	✓		
Flabellum sp.	✓		
Javania sp.	✓		
Madrepora oculata	✓		c
Solenosmilia variabilis	✓		c
Stephanocyathus sp.	✓		
Order Antipatharia			
Antipathes dichotoma	✓		
Bathypathes spp.	✓		a
Leiopathes expansa	✓		
Parantipathes hirondelle	✓		
Stauropathes punctata	✓		
Stichopathes gravieri	✓		

Taxon	Sessile	Mobile	Source
Telopathes magna	✓		
Trissopathes sp.	✓		
Order Actinaria			
Actinauge sp.	✓		c
Actinernus michaelsarsii	✓		
Actinoscyphia sp.	✓		d
Pheliactis sp.	✓		
Order Ceriantharia			
Cerianthus spp.	✓		
Order Zoantharia			
Epizoanthus sp.	✓		*d*
Epizoanthus paguriphilus	✓		
Bullagummizoanthus sp.	✓		
Parazoanthus anguicomis	✓		d
Subclass Octocorallia			
Order Alcyonacea	✓		
Acanella sp.	✓		b, c
Acanella cf. arbuscula	✓		a
Acanthogorgia sp.	✓		a, b
Anthomastus grandiflorus	✓		
Anthothela sp.	✓		
Candidella imbricata	✓		
Chrysogorgia sp.	✓		c
Clavularia rudis	✓		
Heteropolypus sol	✓		

Taxon	Sessile	Mobile	Source
Isidella sp.	✓		
Jasonisis sp.	✓		
Keratoisis sp.	✓		
Lepidisis sp.	✓		
Paragorgia ?corallioides	✓		
Paragorgia ?johnsoni	✓		
Paramuricea spp.	✓		
Primnoa resedaeformis	✓		
Radicipes sp	✓		
Swiftia sp.	✓		
Order Pennatulacea			
Distichoptilum gracile	✓		
Halipteris sp.	✓		
Kophobelemnon cf. macrospinosum	✓		
Kophobelmnon stelliferum	✓		
Pennatula aculeata	✓		c
Pennatula cf. grandis	✓		
Pennatula cf. inflata	✓		
Protoptilum spp.	✓		
Umbellula spp.	✓		
Phylum Porifera			
Class Demospongiae			
Axinella sp.	✓		
Geodia macandrewii	✓		
Hexadella dedritifera	✓		d

Taxon	Sessile	Mobile	Source
Hexadella sp.	✓		
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			

Taxon	Sessile	Mobile	Source
Anachalypsicrinus nefertiti		✓	
Atelecrinus helgae	✓		
Endoxocrinus (Diplocrinus) wyvillethomsoni		✓	
Koehlermetra porrecta	✓		
Neocomatella europaea	✓		
Pentametrocrinus atlanticus	✓		
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 sp.	✓		
Order Cidaroidea			
Cidaris cidaris	✓		c, d
Class Holothuroidea			
Bathyplotes natans	✓		
Benthogone rosea	✓		

Taxon	Sessile	Mobile	Source
Laetmogone violacea	✓		
Mesothuria sp.	✓		
Parastichopus tremulus	✓		
Psolus squamatus	✓		
Class Asteroidea			
Asteroschema sp.	✓		
Hippasteria sp.	✓		
Nymphaster arenatus	✓		
Peltaster sp. (as Ceramaster sp.)	✓		d
Plutonaster bifrons	✓		
Porania pulvillus	✓		d
Solaster sp.	✓		
Stichastrella rosea	✓		d
Zoroaster fulgens	✓		
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			

Taxon		Sessile	Mobile	Source
	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 sp. (Barbeled Dragonfish)	✓		
	Synaphobranchus kaupii (Kaup's Arrowtooth Eel)	✓		
	Trachyrincus murrayi (Roughnose Grenadier)	✓		

Taxon	Sessile	Mobile	Source
Trachyscorpia cristulata (Spiny Scorpionfish)	✓		
Phylum Foraminifera			
Order Xenophyophorida			
Syringammina fragilissima		✓	c

Appendix C - Goals, Objectives and Indicators for Marine Protected Areas

Table C.1: Goals, Objectives, Indicators and Success Criteria (GOIS) to support management of marine protected areas (modified from PROTECT, 2009).

Biophysical Goals

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Primary Goal 1 – Ensure the structural integrity of cold water coral habitat	Prevent all activities which cause abrasion and physical damage	Biological – Statistical comparison of percentage cover using visual inspections of coral (before and after control impact [BACI])	Coral percentage cover to remain within percentage cover values calculated for reference sites
		Fisheries – Frequency of vessel activity in marine protected area as shown by vessel monitoring system data	Vessel entry into area = 0
		Other Activities – Level of compliance with terms of scientific research permits issued for study in marine protected area	Compliance with terms of permit = 100 %
		Licensed granted for oil and gas exploration/exploitation	Licenses = 0
		Number of seafloor structures/ platforms constructed including associated groundworks in coral fields	Seafloor construction /platforms = 0
		Number of instances of dumping/ lost fishing gear	Instances = 0

Goals (primary, secondary and tertiary)	Specific Objectives	Indices to be measured (necessary to judge success)	Success (management criteria
		Number of instances of ship related pollution effects including wrecks/spills and intentional discharge	Instances = 0
Secondary Goal 1 – Restore degraded habitat	Prevent all activities which cause abrasion and physical damage to permit recovery	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
	Cut down recovery time through possible interventions such as artificial reefs /transplantations with due regard to population genetic considerations	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Tertiary Goal 1 – Maintain potential as carbon sink/reservoir (*reference values yet to be defined)		Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna above reference levels*.
Primary Goal 2 – Protect living populations of *Lophelia pertusa* and ensure contributions of local genetic	Prevent all activities which cause unnatural mortality to *Lophelia* populations. Ensure contribution of local genetic diversity to *Lophelia* gene pool.	Calculate proportion of living to dead coral using video or photographic stills	Proportion of living to dead coral maintained at natural levels for Lophelia as estimated from multiple reference sites*. Natural levels defined in time and space to allow for natural shifts linked, for example, to climate change*.

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
diversity to *Lophelia* gene pool*	Maintain environmental quality at levels sufficient to ensure natural viability of living coral polyps within reference limits	Measure relevant oceanographic variables including temporal variation of quantity and quality of suspended particulates in the locality of the reef	Environmental parameters remain at natural levels*.
Primary Goal 3 – Protect associated biodiversity and ecosystem function (including fish populations)	Losses to associated biodiversity and ecosystem function prevented, maintenance of trophic structure complexity ensured.	Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna above reference levels*.

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Secondary Goal 3 – Restore degraded coral habitat areas to level sufficient to support natural associated faunal assemblages (including fish species) similar to those found in non-degraded habitat	Prevent all activities which cause abrasion and physical damage to permit recovery Cut down recovery time through possible interventions such as artificial reefs /transplantations with due regard to population genetic considerations.	Document presence of coral re-growth in impacted areas Document presence of coral re-growth in impacted areas	Instances of re-growth > 0 Instances of re-growth > 0
(*reference values yet to be defined)			

Socio-Economic Goals

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Primary Goal 1 – Livelihoods enhanced or maintained	Ensure the option value (reservoir) of coral habitat for potential biodiscovery. Maintain contribution of coral habitat supporting local populations of exploitable fish stocks (refuge and stock reservoir etc.)	Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna above reference levels*. Cut down recovery time through possible interventions such as artificial reefs/ transplantations with due regard to population genetic considerations. Document presence of coral re-growth in impacted areas. Instances of re-growth > 0 Maintain contribution of coral habitat supporting local populations of exploitable fish stocks (refuge and stock reservoir etc.)*. Census exploitable fish stocks in locality of coral habitat.

Goals (primary, secondary and tertiary)	Specific Objectives	Indices to be measured (necessary to judge success)	Success (management criteria
		Census exploitable fish stocks in locality of coral habitat.	Fish populations of commercial species maintained or enhanced
Primary Goal 2 – State compliance with EU and international obligations and maintenance of international standing	Ensure that the State is compliant and not subject to EU penalties or private lawsuits. Economic imperative of not drawing down fines or engendering lawsuits.	Number of notified breaches of EU and international obligations with fiscal penalties	Number of breaches with fiscal penalties = 0

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Primary Goal 3 – Maintain as scientific reference area and increase scientific knowledge to ensure long-term dividend of research investment is realised	Scientific understanding increased through research and standardised monitoring approaches – future link with Marine Strategy objectives.	Instigate long-term sampling and monitoring programme with standardised sample design.	Long-term data-sets collected are robust and amenable to time series analysis.
Secondary Goal 1 – Increase understanding of climate change processes	Undertake paleo-climate studies	Develop appropriate coral skeletal isotopic proxies	Improved understanding of climate change

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Primary Goal 4 – Environmental awareness and knowledge enhanced	Level of scientific knowledge held by the public increased	Monitor public exposure to available new science related information through public questionnaires	Questionnaires reveal increase in public awareness and knowledge of coral reefs over time
Tertiary Goal 1 – Ensure non-monetary benefits	Aesthetic value enhanced or maintained (education, tourism)	Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna reference levels*.
(*reference values yet to be defined)			

Activity Specific Monitoring - Static Gear Fishing

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Primary Goal 1 – Ensure the structural integrity of cold water coral habitat	Prevent all activities which cause abrasion and physical damage	Biological: Statistical comparison of percentage cover using visual inspections of coral (before and after [BACI])	Coral percentage cover to remain within percentage cover values calculated for reference sites
		Fisheries: Frequency of vessel activity in marine protected area as shown by vessel monitoring system data	Compliance with terms of permit = 100 %
		Number of instances of dumping/ lost fishing gear	Instances = 0
		Number of instances of ship related pollution effects including wrecks/ spills and intentional discharge	Instances = 0
		Document presence of coral re-growth in impacted areas	Instances of re-growth > 0

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
	Cut down recovery time through possible interventions such as artificial reefs /transplantations with due regard to population genetic considerations	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
Tertiary Goal 1 – Maintain potential as carbon sink/reservoir		Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects	Structural integrity of reefs and associated mega-fauna above reference levels*.

Goals (primary, secondary and tertiary)	**Specific Objectives**	**Indices to be measured (necessary to judge success)**	**Success (management criteria**
Primary Goal 2 – Protect living populations of *Lophelia pertusa* and ensure contributions of local genetic diversity to *Lophelia* gene pool	Prevent all activities which cause unnatural mortality to *Lophelia* populations. Ensure contribution of local genetic diversity to Lophelia gene pool.	Calculate proportion of living to dead coral using video or photographic stills	Proportion of living to dead coral maintained at natural levels for Lophelia as estimated from multiple reference sites*. Natural levels defined in time and space to allow for natural shifts linked, for example, to climate change*.
(*reference values yet to be defined)			