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agus Fiadhúlra
National Parks and Wildlife Service

Reef Habitat in Irish Intertidal and Near-shore Waters

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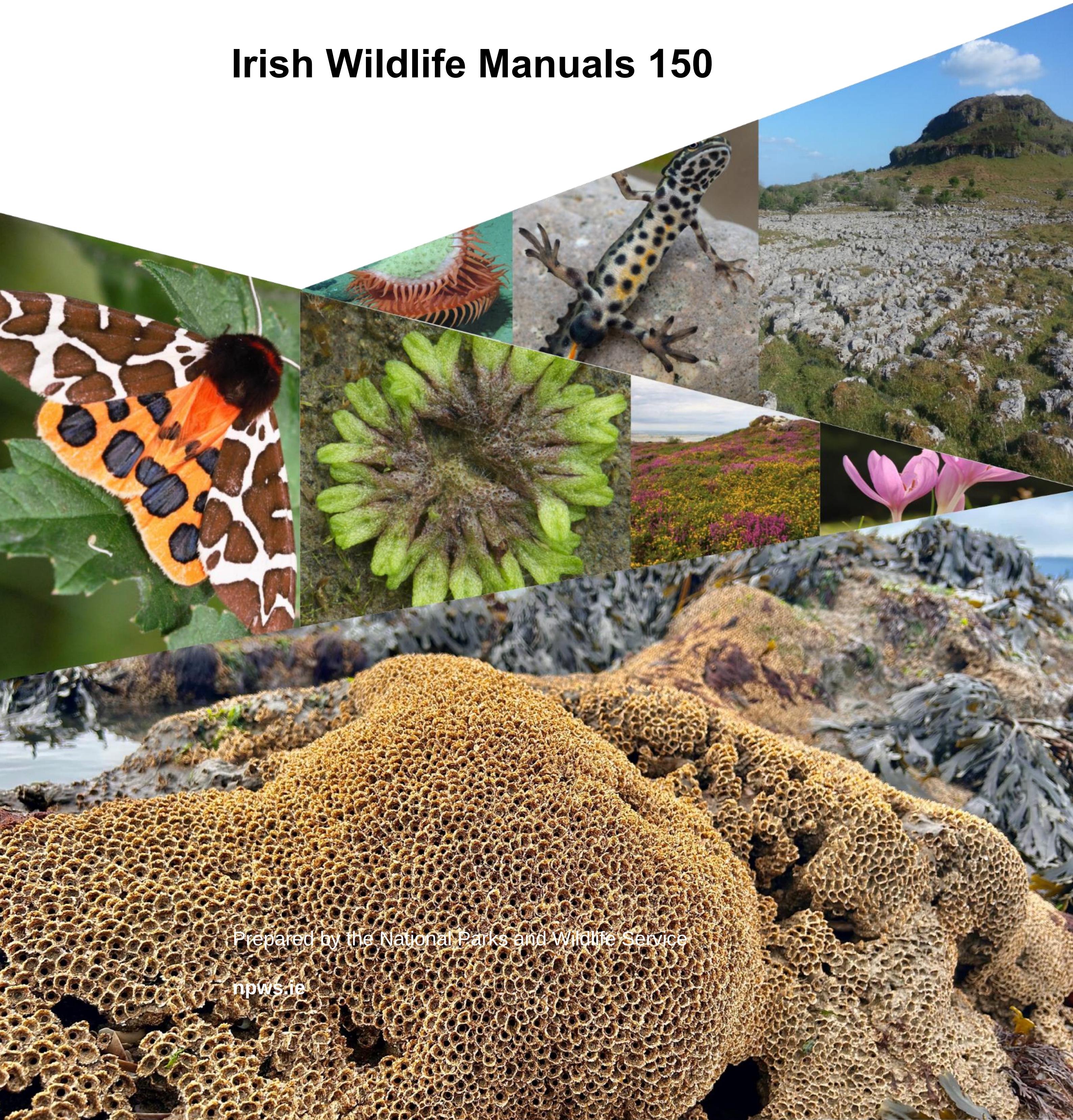

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Front cover, from left to right and top to bottom:

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

Bottom photograph: **Honeycomb Worm** *Sabellaria alveolata* biogenic reef, Duncannon, Co. Wexford, David Lyons.

Reef Habitat in Irish Intertidal and Near-shore Waters

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Executive Summary

Reef habitats are highly important marine habitats, noted for their structural role in coastal areas, and the ability to enhance the diversity and abundance of marine fauna, increase habitat complexity and create opportunities for ecological interactions. However, the current status of reef habitat within the Irish Exclusive Economic Zone (EEZ) is assessed as Inadequate/Stable, primarily due to poor future prospects of structure and function, as a result of the low tolerance of reef habitat to physical disturbance. The aim of this project is to improve the knowledge of the structure, function, and distribution of habitats and communities containing potential Annex I reef habitat within Irish near-shore waters, to a depth of 200 m. In doing so, the project aims to provide a more comprehensive understanding of the location of reef habitat, in order to improve future management, and to enable a more robust assessment of conservation status by improving the knowledge of range, area, structure and functions, and future prospects.

Overall, reef habitats create structures that reach into the water column from the seafloor and can be broadly categorised into biogenic or geogenic reef based on their form. Geogenic reefs are defined by the substratum rather than by a specific biological community, whereas biogenic reefs are defined by the presence of a structure created by organisms themselves. The range of geogenic reefs is determined by physical and geological processes and so, they are extremely variable in structure and in the communities they support. The main biogenic reef-forming species present in Irish near-shore waters are: *Sabellaria alveolata, Sabellaria spinulosa, Serpula vermicularis, Mytilus edulis, Modiolus modiolus, Ostrea edulis, Limaria hians, Lophelia pertusa,* and *Madrepora oculata.* Reefs provide an increase in structural complexity and a cryptic habitat, which allows for the settlement of other species, and provide refuge from predation, competition, and physical and chemical stresses. Reef habitats also represent important food resources for juvenile fish and economically important fish stocks.

The distribution of reef habitat is influenced by a number of physical and environmental factors, including tidal immersion, wave exposure, temperature and salinity fluctuations, and desiccation. Each reef type requires certain environmental conditions. Many biogenic reef-building species form extremely variable community types, with gradation between non-reef and reef biotopes. This presents difficulty when predicting their exact range. Reef habitats in Irish waters range from the intertidal zone to 4500 m below the sea surface and more than 400 km from the coast. In near-shore waters, the overall extent of reef habitat was calculated at 9,474 km^2 in this project compared to the previous extent calculated at 9,146 km^2 based on data collected during the 2013 Article 17 reporting. Three newly documented areas of reef habitat, comprising a mix of both biogenic and geogenic reef, were found during the present study, indicating increased records of reef habitat, especially in areas around the coastline.

In Ireland the 1992 EC Habitats Directive (92/43/EEC) is currently the only legislation providing protection to reef habitats. Under this legislation, a network of Natura 2000 sites was created, where habitats for protection are identified and Special Areas of Conservation (SACs) designated for their protection. Forty-eight SACs have been designated for the protection of Annex I Reef habitat within Irish waters. In recent years, significant levels of survey work have been undertaken to investigate the structure, distribution and extent of these reef habitats in Irish SACs. Following these surveys, a total of 2,204 km^2 of reef habitat is known to occur within SACs in Irish waters.

Using the information gathered, indicators to aid in evaluating the structure and functions of reef habitat have been suggested. Indicators were based on biological, chemical and physical attributes deemed important for regulating the establishment of reef habitats. These indicators may be useful for future monitoring assessments of reef distribution, structure and functions within Irish waters. To improve the management and protection of reef habitats, future work should prioritise investigations of how ecological processes in coastal ecosystems respond to extreme events and which features may determine their resilience and recovery. A more thorough understanding of anthropogenic impacts to species, within different habitats, is also

needed to fully understand the effects of disturbance to biogenic and geogenic reef. A clear understanding of the environmental requirements for reef proliferation is also essential for determining reef location and for future conservation of reef habitats.

1 Introduction

The National Parks and Wildlife Service (NPWS) commissioned this project to develop and improve the understanding of the habitats and communities present in Irish near-shore waters identified as containing potential Annex I reef habitat, defined according to the EC Habitats Directive (92/43/EEC). Reef habitats, both biogenic and geogenic, are highly significant marine habitats, noted for their important structural role in coastal areas, ability to enhance the diversity and abundance of marine fauna, increase habitat complexity and create opportunities for ecological interactions (Gibb *et al.,* 2014).

In order to manage the marine environment, it is necessary for decision makers to have access to suitable tools for identifying the state of marine biodiversity and habitats. The conservation status of a habitat is defined as "the sum of the 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" (Council Directive 92/43/EEC, 1992). The current state of reef habitat within the Irish Exclusive Economic Zone (EEZ) is assessed as Inadequate/Stable, primarily due to poor future prospects of structure and function, as a result of the low tolerance of reef habitat to physical disturbance (NPWS, 2019a, b). As such, it is crucial to understand the functions, and accurate distribution, of these protected marine habitats and their associated species. The conservation status of a natural habitat will be taken as favourable when "its natural range and the areas it covers within that range are stable or increasing, 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 the conservation status of its typical species is favourable" (Council Directive 92/43/EEC, 1992). In order to determine the status of a habitat, its known range, area, structure and functions, and future prospects must all be assessed (NPWS, 2019b).

The assessment of reef status and management of reef habitat is challenging because reef habitats are often patchily distributed and are known to occur in a range of environmental conditions, making a universal assessment difficult. Further to this, many of the biogenic reef-forming species form extremely variable community types, with gradation between non-reef and reef biotopes (Holt *et al.,* 1998).

By improving understanding of the habitats and communities present in Irish near-shore waters identified as containing potential reef habitat, this project will provide a more comprehensive understanding of reef location. This will enable future management of these habitats and assessment of conservation status by improving the knowledge of all four areas of assessment: range, area, structure and functions, and future prospects.

1.1 Background

Reefs are rocky marine habitats or biological concretions which rise from the seabed in the littoral and sublittoral zone. Reefs can be either biogenic or geogenic and are described as "hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone and may support a zonation of benthic communities of algae and animal species" (EU Commission, 2007). Where they extend into the intertidal zone they may be exposed to air at low tide (Irving, 2009).

It is acknowledged that reef habitats encompass three main categories:

- Bedrock reef – continuous outcrops of bedrock which may be of various topographical shapes (Johnston *et al.,* 2002).
- Stony reef – 10% or more of the seabed substratum is composed of particles greater than 64 mm across, *i.e*. cobbles and boulders. The remaining supporting 'matrix' could

be of smaller sized material. The reef may be consistent in its coverage or it may form patches with intervening areas of finer sediment (Irving, 2009).

- Biogenic reef – formed by encrustations, corallogenic concretions and bivalve beds originating from dead or living animals. The main species that can form biogenic reefs in Ireland are Blue Mussels *Mytilus edulis*, Horse Mussels *Modiolus modiolus*, Ross Worm *Sabellaria spinulosa,* Honeycomb Worm *Sabellaria alveolata*, the serpulid worm *Serpula vermicularis*, and cold-water corals such as *Lophelia pertusa* and *Madrepora oculata* (Johnston *et al.,* 2002; Forde *et al., In prep.*).

A variety of subtidal topographic features are included in this habitat complex such as: hydrothermal vent habitats, sea mounts, vertical rock walls, horizontal ledges, overhangs, pinnacles, gullies, ridges, sloping or flat bedrock, broken rock and boulder and cobble fields (Irving, 2009). This variety of topographical features is what contributes to reef complexity and heterogeneity, which makes this habitat so challenging to monitor.

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, b). This habitat is often host to species or communities that may be sensitive to ecological change and may also make a very significant contribution to ecological diversity (MERC, 2010).

Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (known as the EC Habitats Directive) is a European agreement which provides a legal framework for the protection of a range of habitats and species which are considered to be of European importance. It has become a highly important piece of legislation governing the conservation of biodiversity in Europe. The Directive requires member states to implement Special Areas of Conservation (SACs) that support and protect habitats listed in Annex I and species listed in Annex II of the Directive. One such Annex I habitat is 'Reefs' (Habitat Code: 1170) (Irving, 2009; Forde *et al., In prep.*).

Under Article 17 of the EU Habitats Directive, member states must report to the European Commission on the Conservation Status of the listed habitats and species every six years. Additionally, there is an obligation for states to report on the implementation of the measures taken to ensure the protection of annexed species and habitats. These reports must identify the area, range, structure and functions, and future prospects of the habitats and evaluate their Conservation Status. In 2019, Ireland's Department of Culture, Heritage and the Gaeltacht submitted the third national Article 17 assessment which included an assessment of the Annex I reef habitat in Irish waters. Consequently, the current state of reef habitat within the Irish EEZ was assessed as Inadequate/Stable (NPWS, 2019a, b). This was partly due to the low tolerance of this habitat to physical disturbance but also due to significant information gaps relating to the distribution, structure and functions of this habitat, impairing future conservation efforts (Forde *et al., In prep.*).

1.2 Aims and Objectives

The aim of this project is to increase the knowledge base for the national assessment of intertidal and near-shore reef as required under Article 17 of the Habitats Directive. This will be done by carrying out a desk-study on the distribution, ecological requirements and susceptibilities to pressures of intertidal and subtidal reefs in Irish waters to 200 m depth. In doing so, the project aims to provide a more comprehensive understanding of the location of reef habitat within Irish near-shore waters in order to improve future management of these habitats and to enable a more robust assessment of conservation status by improving the knowledge of all four areas of assessment: range, area, structure and functions, and future prospects.

The objectives of the project are to:

- Collate known and historical data on the distribution of reef habitat;

- Create a supporting GIS database to update the known distribution of reef habitat;
- Provide a confidence assessment to determine the suitability of data to inform on the range and area of reef habitat;
- Research known ecological and environmental requirements of both geogenic and biogenic reef habitat;
- Classify associated faunal assemblages, both sessile and mobile;
- Suggest indicators which may aid in the evaluation of structure and functions; and
- Highlight potential pressures and threats to intertidal and shallow subtidal reef and indicate how they may result in changes to the ecological structure and functions of these habitats.

In this investigation, these objectives will be achieved through a review of existing scientific literature and spatial data, and the collation of information relating to the ecology and distribution of reef-forming species and spatial information which could be mapped.

It is anticipated that following the completion of this project, a more comprehensive understanding of the location of reef habitat within Irish near-shore waters will be gained. The production of spatial maps to illustrate the extent of reef habitat would serve to demonstrate this. The above elements of the study are likely to have considerable importance for future management of these habitats and for assessing conservation status under Article 17.

2 Area and Range of Reef Habitats within Irish Waters

2.1 Reef in Irish Waters

Reef habitat in Irish waters ranges from the intertidal zone to 4500 m below the sea surface and more than 400 km from the coast. There are a number of physical and environmental factors that control the distribution of this habitat type including tidal immersion and wave exposure, freshwater influences, fluctuations in temperature and desiccation.

Reef can be broadly categorised into biogenic or geogenic reef based on their form. They are rocky substrates and biogenic concretions, which arise from the sea floor in the sublittoral zone but may extend into the littoral zone where there is typically an uninterrupted zonation of benthic communities of algae and animals species including concretions, encrustations and corallogenic concretions (Irving, 2009). Both biogenic and geogenic reefs support diverse assemblages of non-coral sessile epifauna (*e.g.* bryozoans, tunicates, anemones and sponges) and mobile faunal communities typically dominated by echinoderms, crustaceans and fishes (NPWS, 2019a, b). Descriptions of each reef type considered in this study are shown in the sections below.

2.1.1 Geogenic Reef

Bedrock and stony reefs are both types of geogenic reef. Geogenic reefs are formed by non-biogenic rocky substrata and occur where the bedrock or stable boulders and cobbles arise from the surrounding seabed, creating a habitat that is colonised by many different marine animals and plants (Forde *et al., In prep.*). Rocky reefs can be highly variable in terms of both their physical structure and the biological communities that they support. They are typically characterised by communities of attached algae (when shallow enough so sufficient light can penetrate to allow photosynthesis) and faunal species such as corals, sponges and sea squirts. They also give shelter to fish and crustaceans such as lobsters and crabs (Irving, 2009).

2.1.2 Biogenic Reef

Holt *et al.* (1998) define biogenic reef as “solid, massive structures which are created by accumulations of organisms, usually rising from the seabed, or at least clearly forming a substantial, discrete community or habitat which is very different from the surrounding seabed. The structure of the reef may be composed almost entirely of the reef building organism and its tubes or shells, or it may to some degree be composed of sediments, stones and shells bound together by the organisms.”

Biogenic reef is that generated by the accretions of animals, for example encrustations, corallogenic concretions and bivalve beds originating from dead or living animals and typically increases the structural complexity beyond the surrounding areas and result in greater biodiversity for the local habitat (NPWS, 2019a).

In inshore areas, biogenic reefs may be formed by the protective structures of annelids such as the Honeycomb Worm *Sabellaria alveolata* (NPWS, 2019a). The most extensive and abundant subtidal polychaete reefs are often formed by the Ross Worm *Sabellaria spinulosa* which is widespread around the British Isles, particularly in the North and Irish Seas (Johnston *et al.,* 2002). Biogenic reefs formed by other polychaete species, such as *Serpula vermicularis* which form calcareous reef structures, are comparatively rare and have only been recorded in sea lochs off the west coasts of Scotland and Ireland (Sanders *et al.,* 2016). Other species responsible for forming biogenic reefs include the Blue Mussel *Mytilus edulis,* the Horse Mussel *Modiolus modiolus,* the Native Oyster *Ostrea edulis*, and the Flame Shell *Limaria hians (*Hall-Spencer & Moore, 2000a; Johnston *et al.,* 2002; OSPAR, 2009c).

In offshore waters, deep-water reefs are formed by a range of species including stony Scleractinian corals. In North Atlantic waters, the most common of these are *Lophelia pertusa* and *Madrepora oculata* (Davies & Guinotte, 2011; NPWS, 2019a).

This project considered biogenic structures formed by the following reef-building species, which are considered to be the main biogenic reef-forming species present in Irish near-shore waters to a depth of 200 m:

- *Sabellaria alveolata*
- *Sabellaria spinulosa*
- *Serpula vermicularis*
- *Mytilus edulis*
- *Modiolus modiolus*
- *Ostrea edulis*
- *Limaria hians*
- *Lophelia pertusa*
- *Madrepora oculata*

The biological attributes of each of these species and the rational for their inclusion is discussed in more detail in Section 3.

It is acknowledged that other species in Irish waters may have the potential to form reef-like structures (*e.g*. mat-forming amphipods such as *Ampelisca* spp., the polychaete, *Lanice conchilega* and bivalve *Musculus discors)*, however, they were excluded from this report as they fall outside the scope of the project and do not constitute reef according to the definition by Holt *et al.* (1998).

2.2 Distribution

This section aims to gather spatial data in order to map the potential location of reef habitat in Irish waters. Understanding of the spatial range, scale and patterns of reef habitat and species as well as the distribution of ecosystem components considered critical to ecosystem generation is important for future management. For the purposes of this project, biogenic and geogenic reef habitat and biogenic species records were sourced for the purpose of mapping. Data were initially gathered through a data mining exercise before the collated data layers were mapped. The outputs of these exercises are discussed in finer detail in the following sections.

2.2.1 Data Mining

In order to map potential reef locations, all available known reef records were sourced through a data mining exercise. A variety of geographic databases and online mapping facilities were searched for data potentially suitable for mapping reef location and/or other critical biotic components, *e.g*. species location. Marine geographic information data can be viewed and acquired from a range of data portals, including European funded data networks, governmental bodies, academic institutions, conservation agencies and consultancies. Marine geographic data types include point data (*e.g*. species distribution data), polygon data (*e.g*. predicted seabed substrate and habitat) and one-dimensional raster layers of the seabed (*e.g*. remotely-sensed bathymetry data).

A non-exhaustive geographic data inventory for reef habitats in the Irish EEZ is provided in Appendix 1. While most of these data were freely available, some required registration, while others were restricted to privileged users or subscription services. Data sources were included regardless of if they were modelled habitat or from in-situ observations.

The individual layers which were fed into the mapping outputs are summarised in Appendix 1.

Within the scope of this project, data were considered suitable if they:

- provided a direct measure or proxy for biotic and abiotic components of reef habitat;
- fully covered all or some of the relevant area of the Irish EEZ; and
- were already digitised and/or processed into a meaningful data layer.

The results of the data mining exercise, mapped as a distribution for each data layer, are presented in Figure 1. Expanded details of each data layer are available in Appendix 1.

2.2.2 Methods of Mapping Reef Distribution

Potential reef location maps were created by combining the component data layers as point and shapefiles in ArcGIS (version 10.3). Each layer was overlain and clipped to the 200 m depth contour line and to the Irish EEZ (defined as the maximum spatial extents for consideration in this project). Data from Northern Ireland was excluded from the data mining exercise as it did not fall within the remit of this project. The data shapefiles were then further clipped to show specific areas where reef habitat or species have been mapped. Finally, these data were compared against data previously collected by NPWS as part of the 2013 Article 17 reporting and were mapped as ‘NPWS Article 17 Reef Extent’ (NPWS, 2013a, b). For the purposes of this project these data have been used as a baseline for reef location and a comparison for current extent of reef habitat to allow for monitoring of any changes in reef distribution (see Figure 2).

Polygon data of both biogenic and geogenic reef habitat location and point data relating to taxa known to form biogenic reefs were included within this project. It should be noted, with regard to point data, that although the mapped data indicates the presence of the species in an area, it does not necessarily signify the presence of reef habitat or provide information on the density of the species, however they are a useful tool in predicting reef location. Species level data and the uncertainties surrounding it being defined as reef habitat are captured in the confidence assessment (see Section 2.2.3)

For the currently sourced polygon data, the actual extent of reef habitat was calculated using the ‘calculate geometry’ tool in ArcGIS. This provides a minimum extent of reef habitat based solely on reef habitat location. This tool does not take into account point data, and therefore species occurrence, as this data cannot provide an exact measurement of density or size.

2.2.3 Data Confidence Assessment

A confidence assessment has been applied to each of the data sources gathered, in order to evaluate the robustness of each reef distribution record gathered. The confidence assessment assigns confidence scores to data based on quality parameters including data age (vintage), acquisition method, data source, and the degree of ground truthing undertaken, which were added together to derive an overall confidence score. Confidence in the individual data layers, which feeds into the mapping outputs, was assessed using the confidence score matrices. Maps showing data confidence are shown in Figures 3 and 4 and individual layer confidence is summarised in Appendix 1.

Data points which plotted the location of individual species records were assessed and only records that were recorded after 2000 were included in the map. This was to ensure data were as accurate as possible, by removing the likelihood that species may no longer be present in the recorded areas. With regards to habitat data, the oldest record of reef habitat included within the mapping exercise dated from 1990.

The calculated confidence scores were categorised into high, medium or low overall confidence classifications. The assessment was designed to allow evaluation of confidence for all varying data types used in this project, ranging from point data derived from field observations to modelled or inferred polygon data. The results are presented in Figure 3 and Figure 4.

2.2.4 Results

The results of the data mining exercise to gather information on the extent of reef habitat in Irish waters are shown in Figures 1 to 6. Specific information relating to each data layer sourced is presented in Appendix 1. The original extent of known reef habitat distribution, as defined by NPWS Article 17 second assessment reporting (2013a, b) prior to the current study, has also been plotted on the maps for comparison.

Data sourced as part of this investigation indicates that reef habitat appears to be less prevalent on the east coast of Ireland compared to other areas of the Irish coastline, however this could reflect differences in survey effort. Additionally, the majority of reef was found within the 12 nautical mile limit, with comparatively little found in offshore waters (acknowledging the 200 m depth cut-off for the project). From the data sourced as part of the data mining exercise, three clear, newly defined areas of reef habitat were found in addition to previously known reef extent; these were recorded between 2014-2016 and are shown in Figure 5. These three areas lay off the southern coast of County Cork, off the west coast of County Mayo, and to the east in St Georges Channel and the Irish Sea on the boundary between the Irish and English EEZs. The habitat in all three of the areas was classified as shelf sublittoral rock and biogenic reef. Specific biotopes were recorded on the south east coast at County Cork as sponge communities on circalittoral rock (EUNIS biotope code A4.12) and in St Georges Sea as faunal communities of deep, moderate energy, circalittoral rock (EUNIS biotope code A4.27).

One area of previously mapped reef habitat for which no spatial data was found during the data mining exercise was to the northwest of Ireland at the boundary of the EEZ. This area is extensive and its loss from current findings may suggest a reduction in reef habitat in the area. However, this area has previously been mapped as geogenic habitat (Figure 6) meaning it is unlikely to have been completely removed as the extent of rocky reef is unlikely to diminish. A reduction in habitat could occur if sediment has covered the area. Due to the unlikelihood that geogenic habitat will have diminished, the apparent reduction of reef habitat in this area is likely due to data availability.

Records of biogenic and geogenic reef have been mapped and the locations are displayed in Figure 6. Biogenic reef was noted to be particularly prevalent of the west coast of Ireland where instances of *Sabellaria* reef, mussel beds, and cold-water corals were all noted. *Lophelia pertusa*, normally a deeper water species, was seen within the 200 m depth limit with several records of the species off the south west coast.

The extent of reef habitat documented as part of this study was calculated in ArcGIS. A total value of 9,474 km^2 of reef habitat in Irish near-shore waters was calculated based on all the records collated as part of the data mining exercise. This is the predicted extent of reef habitat and does not take into account any species point data as these do not provide information on the range or density of species occurrence. The calculation does not include any previous records of reef habitat, as the extent of these habitats may have changed or diminished over time. The calculation only includes records acquired during this current data mining exercise, carried out in 2017. It should be noted that this figure does not take the confidence assessment into account and the polygons mapped may use interpolation which could lead to an overestimation of reef area. However, due to species data being excluded from analysis it is considered that a net underestimation of reef distribution has been made, and reef habitat is therefore predicted to be higher than the calculated value. Calculation of previous reef extent collected during the NPWS 2013 Article 17 reporting (NPWS, 2013a, b) produced an estimated area of 9,146 km^2 of reef habitat, suggesting that, as a minimum, reef habitat has been maintained. It may also indicate an increase in reef habitat in Irish near-shore waters, however care has to be taken as it may not reflect an absolute increase in reef habitat but be reflective of increased knowledge and survey effort for these habitats.

The highest confidence assessment value was scored by the fine scale habitat mapping at Clew Bay, Kilkieran Bay, Kenmare River and Roaringwater Bay. Some of the data collected as part of the MESH Atlantic Project depicting Cork coastal rock habitats and near-shore habitats in the Celtic Sea also received a high confidence assessment score; this is due to the fact that data is more recent, has been mapped as opposed to interpolated, and has been ground-truthed. Species occurrence data generally received low assessment scores. Although these are likely high quality data recorded from direct field observations, the record indicates the presence of the species and not necessarily the presence of reef habitat. This is reflected in the overall low confidence assessment value. Generally, modelled seabed habitats or data with limited ground-truthing were rated as medium confidence, because although reef is predicted to be in the area, there has not necessarily been direct sampling to confirm this.

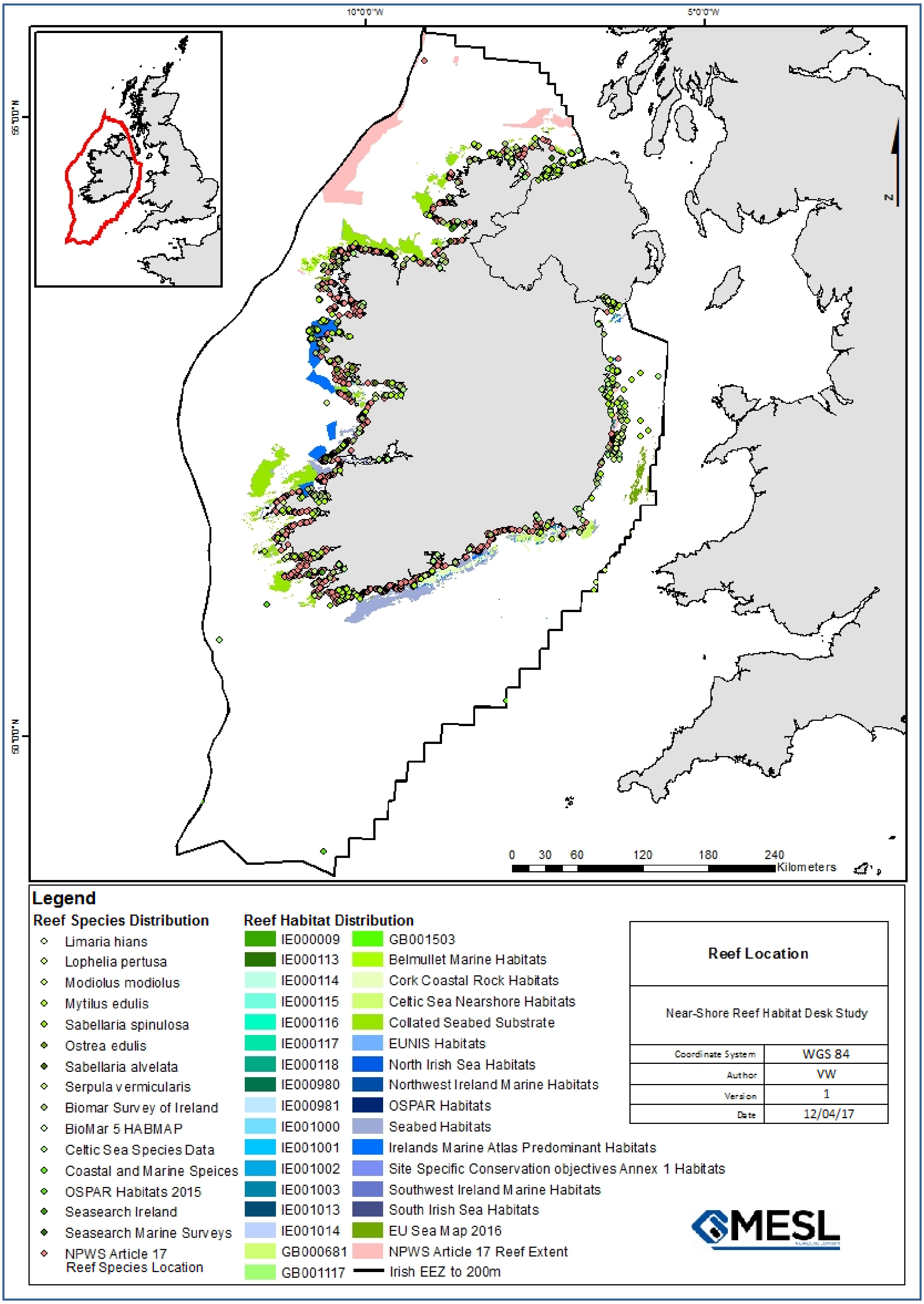

Figure 1 Breakdown of data layers showing the location of biogenic and geogenic reef within the Irish Exclusive Economic Zone to 200 m depth, as defined by the data mining exercise undertaken as part of this project.

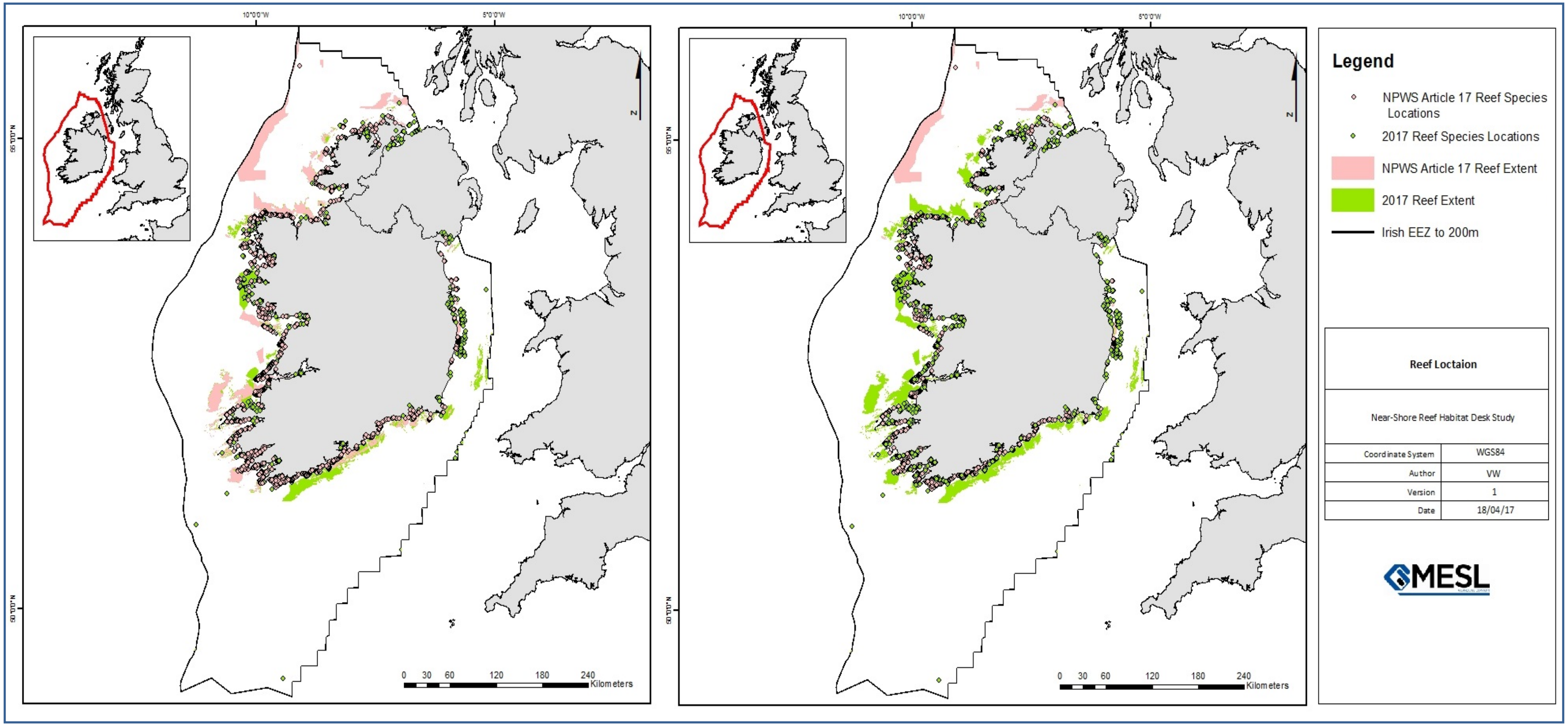

Figure 2 Location of biogenic and geogenic reef habitat within the Irish Exclusive Economic Zone to 200 m depth comparing previous records of reef habitat defined by NPWS Article 17 Reporting in 2013 shown against 2017 reef extent as defined by the data mining exercise undertaken as part of this project. 4A displays previous records of reef habitat and indicates newly recorded areas of reef. 4B displays all reef habitats found during the 2017 data mining exercise and indicates previous data that was not found during the current study.

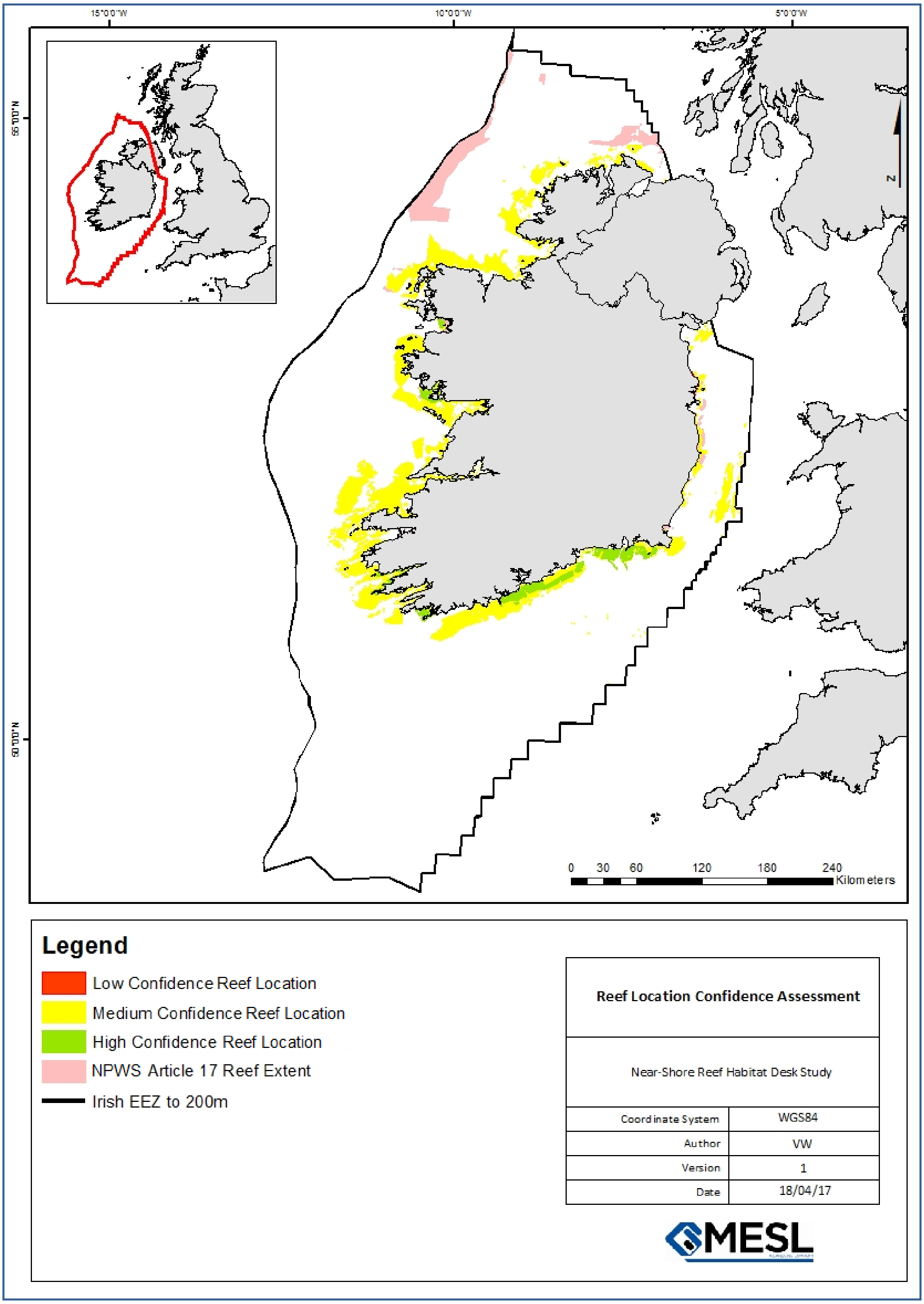

Figure 3 Location of biogenic and geogenic reef habitat within the Irish Exclusive Economic Zone to 200 m depth with the assigned confidence assessment of each habitat polygon data layer.

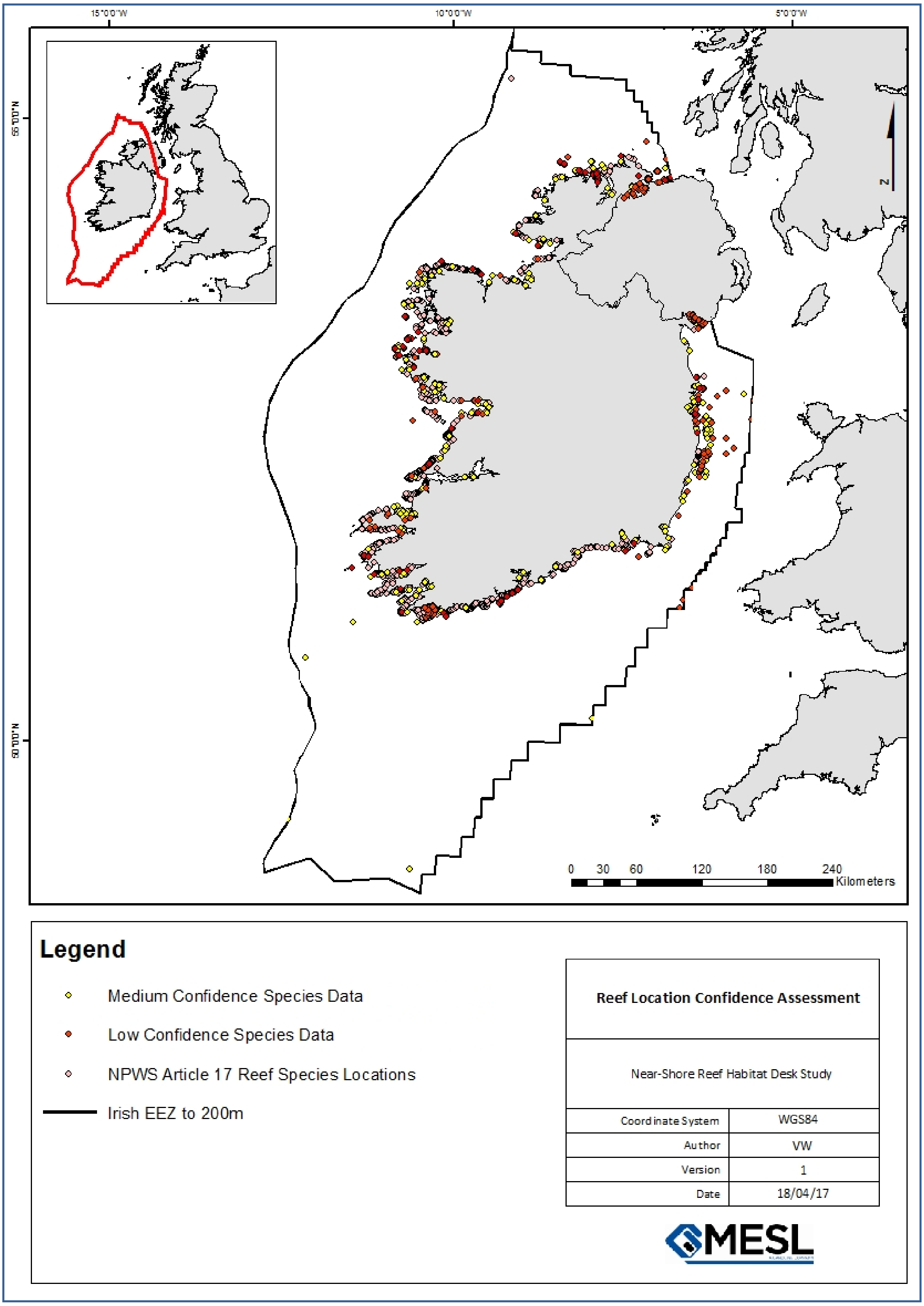

Figure 4 Location of biogenic and geogenic reef habitat within the Irish Exclusive Economic Zone to 200 m depth with the assigned confidence assessment of each species data point layer. No species data were assigned a high confidence score.

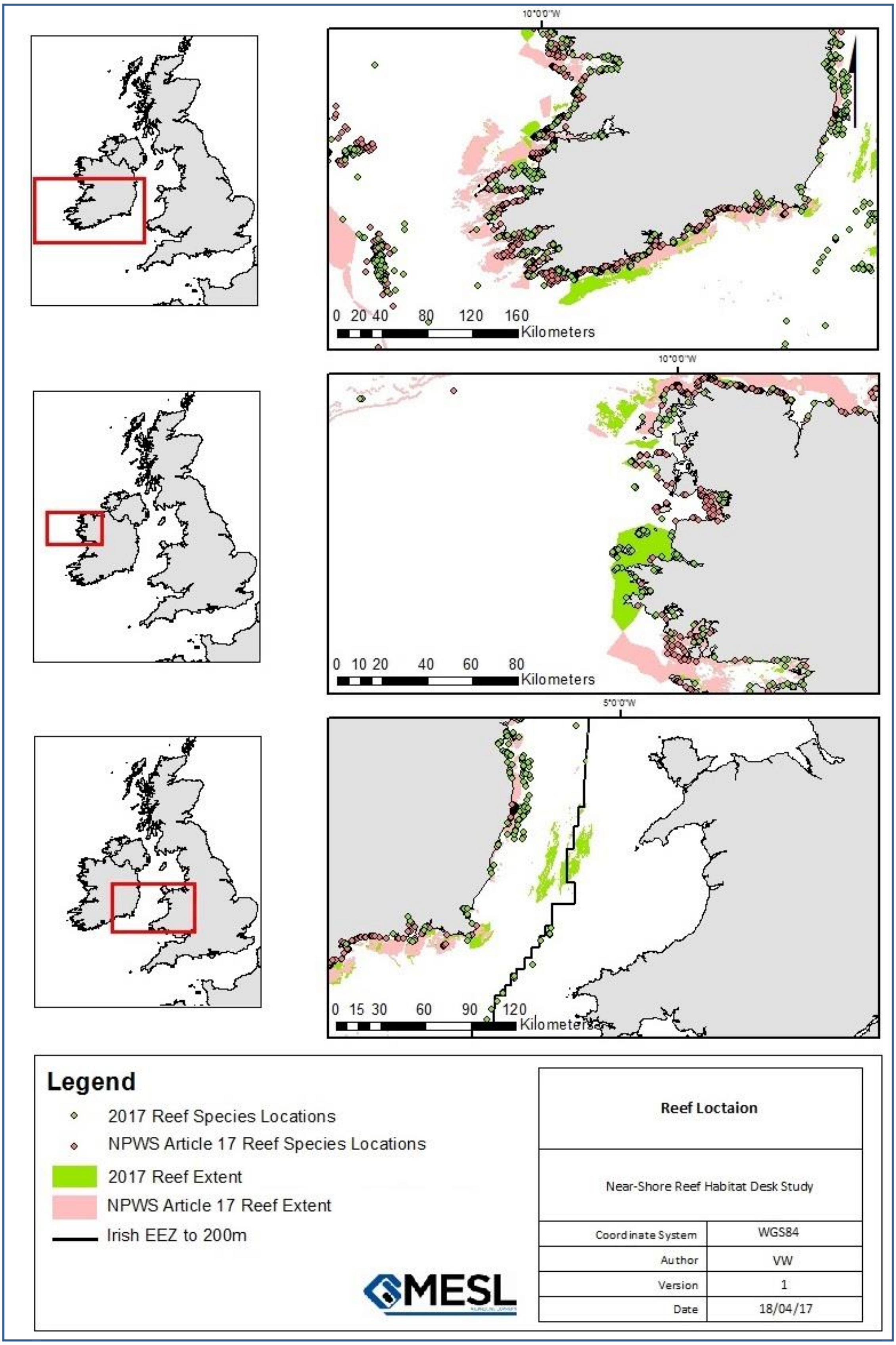

Figure 5 Location of three newly defined areas of biogenic and geogenic reef habitat within the Irish Exclusive Zone comparing previous records of reef habitat defined by NPWS Article 17 Reporting in 2013 shown against 2017 reef extent as defined by the data mining exercise undertaken as part of this project.

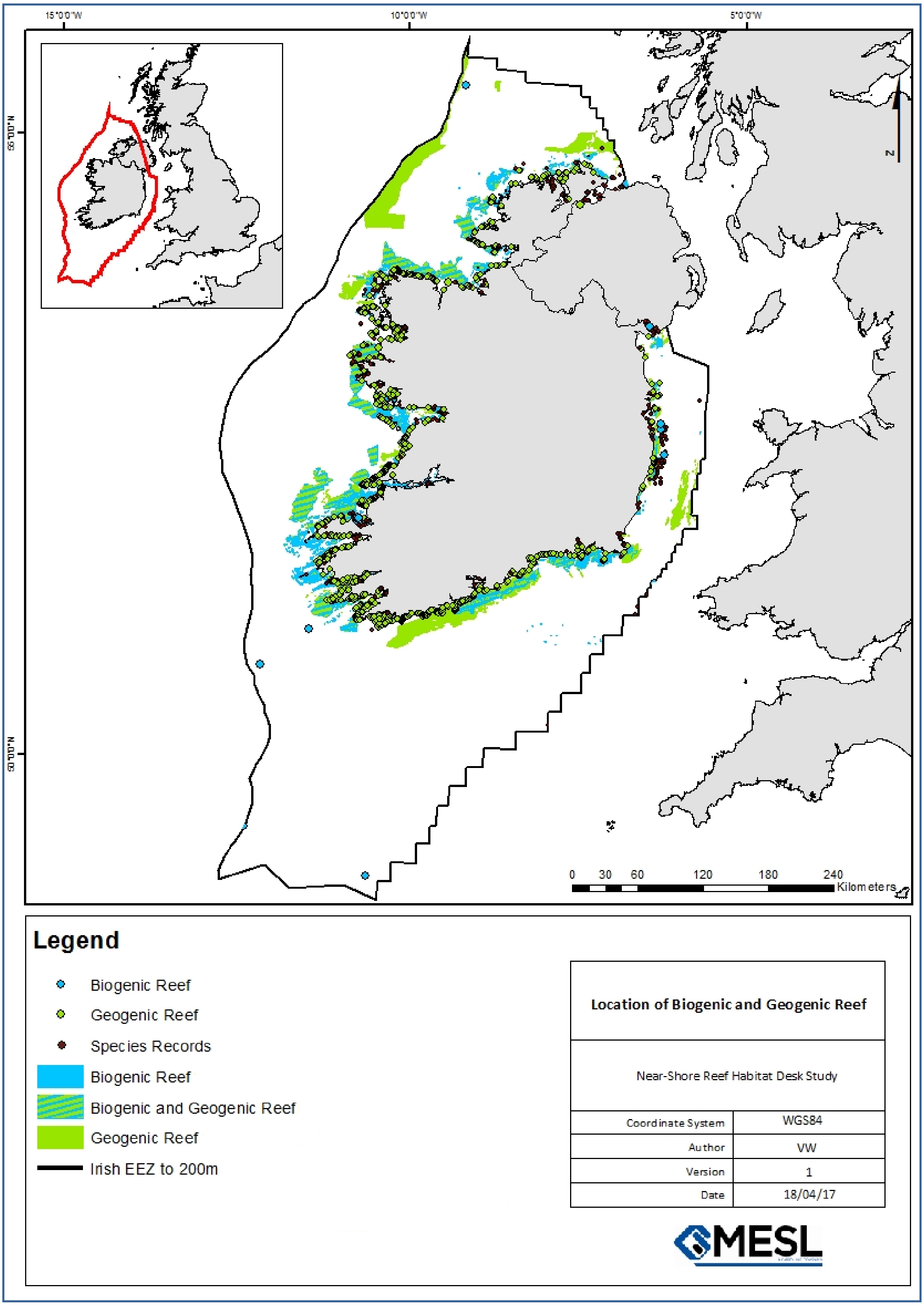

Figure 6 Location of biogenic and geogenic reef habitat within the Irish Exclusive Economic Zone to 200m depth. Species Records represent occurrence of reef-forming species but do not specifically identify reef habitat.

2.2.5 Limitations and Constraints of Mapping Reef Distribution

The maps of potential reef location presented in this project are subject to a number of limitations, caveats, and constraints as a result of features of the various datasets that were used.

The results presented reflect the time and resources that have been made available for this project, and the outputs are based only on the data which was available as part of the literature review and data mining exercise undertaken. Results and mapped reef location are therefore also a reflection of survey effort.

Point data relating to taxa known to form reef habitat were included within this project, however it should be noted that although the mapped data indicates the presence of a reef-forming species in an area, it does not necessarily signify the presence of reef habitat or provide information on the density of the species. These data should therefore be interpreted with caution; however, they are a useful tool in predicting potential reef location. To remove the likelihood that species may no longer be present in the recorded areas, and to ensure data were as accurate as possible, data points plotting the location of individual species were selected so that only records recorded after the year 2000 were included in the map. However, any changes in reef extent since this date may be unaccounted for.

The data layers used in generating the maps are in some cases predictive, interpolated, or based upon numerical models, thus may not be considered wholly accurate. This is reflected in the data layer confidence score. This may have resulted in an over estimation of the reef extent recorded in this project. However, it is plausible that this is balanced by the underestimation of reef habitat that may have occurred due to the assumption that the presence of reef building species in point data was not a precursor for reef habitat. When viewing potential reef habitats from the data collated as part of this project, the confidence assessment of the data should be taken into account.

The EUSeaMap predicted European Nature Information System (EUNIS) habitat is a valuable geographic information layer and has been used in previous efforts to map the spatial patterns of ecosystem services in the North East Atlantic. Though this dataset aids in mapping the location of geogenic reef, it should be noted that some layers do not provide the detail needed to map specific habitats and biotopes, as it is limited to EUNIS Level 3 (*e.g.* A3.1, Atlantic and Mediterranean high energy infralittoral rock). It is therefore likely that this layer represents an overestimate of the specific area of reef habitat. Further ground-truthing may be needed to provide greater detail to improve the quality of mapped habitats.

Due to the inherent difficulty associated with surveying deep-water ecosystems, knowledge of the extent of coral distributions is poor. Therefore, many of the layers use predictive habitat modelling techniques to create maps of potential distribution and to identify the ecological requirements of deep-water corals. These modelled distribution maps are useful, and many use ground-truthed data to support the model. However, it should be noted that these data can overestimate the extent of habitat and should be assessed with caution.

It should also be noted that additional privately owned data sources were not made available for use in this project. Should these data sources be made available in the future, then the outputs of this project could be updated. It is likely that the accuracy of maps could be improved if supplemented with this data.

2.2.6 Reef Habitat Distribution Summary

Based on the data collated as part of this project, reef habitat extent in Irish waters was calculated at 9,474 km^2 (subject to the caveats and commentary presented above) compared to previous extent calculated at 9,146 km^2 based on data collected during the 2013 Article 17 reporting. This slight increase may suggest an increase in reef habitat or may be a result of increased survey effort in the area.

Three newly documented areas of reef habitat were found during the present study, indicating increased records of reef habitat especially in areas around the coastline. However, the current project did not record the presence of reef within the north western portion of the EEZ, which could suggest a reduction in reef habitat within deeper waters, although it should be noted that this may also be due to a lack of available data sources.

Of the newly defined areas, there was a mix of both biogenic and geogenic reef, which shows diversity within the habitats and likely increase in structural complexity and therefore likely associated diversity in the area.

3 The Structure and Functions of Reef Habitats in Irish Waters

The second part of this project investigates the known ecological and environmental requirements of reef habitat and examines faunal assemblages associated with both geogenic and biogenic reef. Section 3 also identifies significant knowledge gaps in relation to reef habitats and suggests indicators which may assist in the evaluation of subtidal reef.

As part of the requirements for the assessment of Annex I reef habitat and to monitor conservation status, it is essential for decision makers to have access to suitable tools for identifying the state of marine biodiversity and habitats. The conservation status of a habitat is determined by “the sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions” (Council Directive 92/43/EEC, 1992). Therefore, it is important to have knowledge of the ecological and environmental requirements that allow for reef proliferation, in order to assess areas in which reef may develop. Following from this, it is important to understand the functions and ecosystem services that reef structures provide to the marine environment in order to understand their conservation value. Finally, the conservation status of a natural habitat will not be taken as favourable until “the conservation status of its typical species is favourable” (Council Directive 92/43/EEC). This cannot be assessed until there is a thorough understanding of the communities typically associated within these habitats.

3.1 Ecology and Biodiversity of Biogenic and Geogenic Reefs

A literature review was conducted to source information on the biotic and abiotic components of both geogenic and biogenic reefs. This information was obtained to highlight environmental parameters which allow for proliferation of reef habitats and to further understand the physical, biological and chemical requirements and drivers of biogenic reef-forming species and geogenic habitats. As part of this task, faunal assemblages associated with reef habitat, including mobile species, were also examined.

Current pressures and threats to both intertidal and subtidal reef were identified and conservation methods being applied to the protection of these habitats were assessed. These are discussed in Section 4 and Section 5.

3.1.1 Literature Review Methodology

3.1.1.1 Literature Gathering

When undertaking the literature review process, a preference was given to information sourced from peer-reviewed journal articles. Multiple electronic databases (Science Direct, Web of Knowledge, Wiley Online Library) were searched using a list of identified key words to ensure that all databases were thoroughly interrogated, and a systematic approach to the literature review was followed.

A ‘grey literature’ search (*i.e.* non peer-reviewed literature, such as articles, theses, technical reports, agency publications *etc*.) was also undertaken following the same process as that used for peer-reviewed information. The grey literature search was conducted using the Google and Google Scholar search engines and Government agency websites (such as JNCC, Natural England, Cefas, MarLIN, *etc*.).

Sources relating to information for Ireland only were prioritised, as the focus of the project was to map reef locations within Irelands EEZ; however, sources from the UK were also widely used. In some cases, the search widened beyond the UK to locate information relevant to the research topic.

3.1.1.2 Data Logging Pro-forma

Information collated during the literature review was entered into a data logging spreadsheet for ease of reference and to allow an evaluation of the sources gathered. Information sourced during the literature review process is presented in Appendix 1.

The relevant information was divided into the following sections:

- **Habitat Characterisation:** List of biotopes, with descriptions and species list, of habitats included under the definition of reef and included within the assessment.
- **Species Lists**: Summary of the species known to be associated with biogenic and geogenic reef habitats.
- **Reference Summary**: Source information, providing full reference, abstract, source type and source confidence. Each reference was given a unique code used to identify the source throughout all sheets.
- **Confidence Assessment**: A representation of the confidence assessment of the source used in the literature review.

3.1.1.3 Literature Review Confidence Assessment

Confidence in the literature and data gathered is a key consideration of this project. Confidence was assessed for individual literature evidence sources using the confidence matrices shown in Table 1a. These matrices use parameters such as source quality (peer-reviewed or non-peer reviewed; shown in Table 1b), and applicability of the study (whether the source is based on data from Ireland and relates to specific geogenic or biogenic reef habitats and ecosystem services that are within the project scope; shown in Table 1c). All confidence scores were assigned by the project team undertaking the literature review using judgement to ascertain a confidence score in accordance with the protocol presented.

Overall confidence was based on the lowest common denominator in confidence from the two source tables, as shown in Table 1a (for example, a source with a high quality score and a medium applicability score would have an overall confidence of medium). Confidence classifications were consequently recorded in the Reference Summary worksheet for each individual source.

Table 1a Overall confidence of individual evidence sources based on combining both quality and applicability, as outlined separately above.

Overall Source Confidence		**Applicability Score**		
		Low	**Medium**	**High**
Quality Score	Low	Low	Low	Low
	Medium	Low	Medium	Medium
	High	Low	Medium	High

Table 1b Confidence assessment of the quality for the individual evidence sources.

Individual Source Confidence	**Quality Requirement**
High	Published, peer reviewed articles Or Grey literature reports by established agencies
Medium	Does not fulfil 'high' requirement but methods are fully described, are considered fit for purpose and to a suitable level of detail Or Expert opinion where feature described is well known/obvious
Low	Does not fulfil 'medium' requirement for level of detail and fitness for purpose but methods are described Or No methods adopted and informed through expert judgement

Table 1c Confidence assessment of applicability for individual evidence sources.

Individual Source Confidence	**Applicability Requirement**
High	Study based on Irish and British data Or Study based on exact feature listed (species, biotope or habitat)
Medium	Study based in Ireland or UK but uses proxies for reef species, biotope or habitat Or Study not based in Ireland or UK but based on exact reef species, biotope or habitat
Low	Study not based on Ireland or UK data Or Study based on proxies for reef species, biotope or habitat

3.1.1.4 Summary of Literature Review

Over 180 peer reviewed and grey literature sources were appraised as sources of information for this project. The majority of information gathered to identify the physical, biological and chemical requirements of biogenic and geogenic reef habitats, associated species, and the current pressures and threats to reef habitats were sourced from peer reviewed and grey literature. In some cases, the information obtained from scientific journals was based upon research that was carried out in comparable temperate regions outside of Ireland and the UK, but was considered to be applicable to the project.

3.2 Results: Ecology and Biodiversity of Biogenic and Geogenic Reefs

This study considers the structure and functions of intertidal and near-shore reefs down to 200 m depth by using published sources to determine the physical, chemical, and biological requirements of reef habitat, the services which reef habitats provide, and the known community associations. These factors are essential for understanding ecosystem function and recovery potential following a disruptive event and for making recommendations for conservation and management practices. The major findings, following the literature review, are presented below.

3.2.1 The Physical, Chemical and Biological Requirements for the Formation of Biogenic Reef

The availability of hard substratum has been shown to be an important factor influencing the proliferation of reef habitat, as it provides essential space for the initial settlement of larvae (Forde *et al., In prep.*). Several studies (Wilson, 1979a, b; Freiwald *et al.,* 1999; Forde *et al., In prep.*) have related the occurrence of large reef formation to the availability of hard substratum, enabling reef propagules to settle, grow and coalesce into extensive areas of reef.

An overview of the ecological and environmental requirements of biogenic reef habitats and species is presented in Table 2. Summaries of the requirements of each species are presented below.

The Ross Worm *Sabellaria spinulosa* is a tube-building polychaete, found predominantly from the sublittoral fringe to approximately 40 m depth in the subtidal zone (Holt *et al*. 1998). Although individuals can occur intertidally, dense populations are found almost entirely subtidally and there are no reports of intertidal reef in Ireland. It is found most commonly along European coasts and is widespread around Ireland and the UK, particularly in the North and Irish Sea. *S. spinulosa* can occur as isolated individuals, small aggregations or large encrusting reefs up to 60 cm high and that cover extensive areas (Holt *et al*., 1998; Gibb *et al.,* 2014). *S. spinulosa* is capable of growing on a variety of substrata, including kelp holdfasts, rock, and less consolidated sediments such as stony sand or gravel, but it requires suspended sand grains in order to form its tubes. Reef communities can therefore become established on a variety of substrates but generally only occur in very turbid areas where sediment is placed into suspension by water movement (Holt *et al.,* 1998).

The natural development of the species is characterised by four phases: larval settlement, growth, stagnation, and destruction. Each developmental stage is influenced by numerous factors such as currents, weather conditions, competition for food and space, and anthropogenic impacts (Vorberg, 2000).

Sabellaria spinulosa is highly ephemeral and cycles of aggregation and degeneration of colonies has been reported over 5-7 year periods. It is also likely to be affected by storms or other forms of disturbance *e.g*. fishing, which can disturb the substratum and break up colonies (Johnston *et al*., 2002).

The Honeycomb Worm *Sabellaria alveolata* is approximately 2-5 cm long and is capable of building tubes up to 15 cm in length. It has a distribution from as far south as the coast of Morocco and north to the Firth of Clyde in Scotland (Holt *et al.,* 1998). This species most commonly forms reefs within the intertidal zone, however, there are limited records of this species forming reefs subtidally, down to 20 m (Mettam *et al.,* 1994; De Grave & Whitaker, 1997; Holt *et al.,* 1998).

Spawning mainly takes place between June and September which, in waters around Ireland, corresponds with increasing water temperatures (Culloty *et al.,* 2010). The species has a life span of 4-5 years (Holt *et al.,* 1998). Once settled, *S. alveolata* builds reef structures from sand grains and shell debris; these may take the form of extensive sheets, hummocks, or more massive and extensive reefs, consisting of honeycomb like masses of worm tubes (Holt *et al.,* 1998).

Due to its growth form, it is limited to areas of hard substrata (stable rocks and boulders or boulder/cobble scars) with moderate to considerable water movement, where there is a good supply of suspended sediments. It does not occur in low salinity areas such as estuaries and is thus restricted to fairly shallow and fully saline conditions (Holt *et al.,* 1998).

Serpula vermicularis, of the family Serpulidae, is a slender, tube-dwelling polychaete generally between 5-7 cm in length. *S. vermicularis* has been recorded from shallow depths on the lower shore down to 250 m, although it is most commonly seen between 2-20 m (Minchin, 1987; Holt *et al*., 1998; Chapman *et al.,* 2007).

After an initial encrusting stage, the worm tubes grow upwards, intertwining to form complex bush-like shapes. These reefs are often discrete structures up to 75 cm high and 1 m across, but adjacent reefs can coalesce to form larger structures (Holt *et al.,* 1998; Poloczanska *et al.,* 2004).

S. vermicularis reefs occur in sheltered, relatively shallow areas, with a limited turnover of water, in order to enable larval retention, and a minimum salinity of 30 ppt (Holt *et al.,* 1998). The presence of reef is influenced by the availability of hard substrata (Chapman *et al.,* 2007). Reefs initially form on hard substrata, such as stones or shells, but can subsequently spread across wider areas. Sedimentation and high levels of silt are detrimental to serpulid recruits by preventing settlement, impeding feeding appendages, and by exhausting supplies of dissolved oxygen (Holt *et al.,* 1998; Cotter *et al.,* 2003).

Recruitment has been recorded from mid-June to mid-December with peak settlement generally occurring between June and September (Cotter *et al.,* 2003; Chapman *et al.,* 2007). Water temperature is known to be a contributing factor to peak settlement in Serpulidae; Chapman *et al*. (2007) found that peak settlement was correlated with water temperatures between 13°C and 15°C.

The Blue Mussel *Mytilus edulis,* is a marine bivalve found from the low intertidal zone to a maximum of 20 m depth, although most commonly at no more than 10 m depth (Holt *et al.,* 1998; Littorin & Gilek, 1999; Mainwaring *et al.,* 2014). Its distribution ranges from the White Sea, Russia, to Southern France and so has a wide range of temperature tolerances. Historically it has often been confused with the Mediterranean Mussel *Mytilus galloprovincialis,* due to similarities in their identification features and overlapping distributions (Tyler-Walters, 2008).

M. edulis is tolerant of a wide range of environmental variables such as temperature (-1 C to 29 C), food supply, water turbidity, and salinity (Holt *et al.,* 1998). Blue Mussel beds are generally recorded between 13-35 ppt but *M. edulis* is one of the few marine invertebrate species that thrive in low saline conditions (4-8 ppt). They are also recorded in weak (<0.5 m/s) to strong (up to 3 m/s) tidal streams and all life stages show high levels of tolerance to low oxygen levels, able to tolerate down to 1.0ml L^{-1} (Holt *et al.,* 1998; Littorin & Gilek, 1999; Mainwaring *et al.,* 2014).

Large reefs form mainly on mixed firm sediments, in relatively sheltered bays and estuaries, where there are strong currents. *M. edulis* reefs are composed primarily of three components: a matrix of interconnected living and dead mussel shells, a bottom layer of accumulated sediments, mussel faeces and pseudofaeces, and a diverse range of associated fauna and flora. Well-developed *M. edulis* reefs generally take the form of hummocks or ribbons, rarely exceeding 30-50 cm in thickness but are often very extensive (Holt *et al.,* 1998; Magorrian & Service, 1998).

Excessive levels of silt and inorganic detritus can be damaging to *Mytilus* if accumulation occurs too heavily within the reef matrix, causing smothering and inhibiting feeding. Storms also play an important part in survival as mussels can become dislodged from the substratum. Intertidal bird predation, especially by eiders and oystercatchers, can also be responsible for the removal of mussels as they form an important part of the diet of these birds (Holt *et al.,* 1998).

The Horse Mussell *Modiolus modiolus* is a slow growing and long-lived bivalve adapted to cold water environments and ranges from the seas around Iceland and Scandinavia south to the Bay of Biscay (Holt *et al.,* 1998; Anwar *et al.,* 1990; OSPAR, 2009a). It is the largest Irish marine mussel, capable of growing to 15-20 cm in shell length and surviving for over 20 years (Anwar *et al.,* 1990). The species does not reach sexual maturity until 3-6 years old, which allows rapid growth to avoid predation in its early years (Holt *et al.,* 1998; Anwar *et al.,* 1990).

M. modiolus can occur as lone individuals, though this is uncommon, as spat preferentially settle in areas with an existing population. This often leads to the formation of dense beds up to 1 m high. When these aggregations extend over 10 m^2, with over 30% coverage, they are classified as biogenic reefs (Holt *et al.,* 1998; OSPAR, 2009a; Morris, 2015).

M. modiolus reefs need some hard substrata to settle but are capable of forming reefs on a variety of sedimentary bottoms, including mixed or muddy sediments. Additionally, *M. modiolus* demonstrate a tolerance to a variety of current regimes, although are often found in tide swept areas, with currents around 1-3 knots. They are found mainly between the shallow infralittoral (~5 m deep) to a maximum of 80 m, in areas of variable salinity, 27-41‰ (Holt *et al.,* 1998; Sanderson *et al.,* 2008; OSPAR, 2009a; Morris, 2015).

Reef habitats create high levels of physical complexity where clumps of dense *M. modiolus* provide substrata for epifaunal communities and spatial refuge for many species. As such, *M. modiolus* reef has been described as one of the most diverse reef types in temperate waters, with faunal assemblages reaching over 200 taxa and at densities exceeding 22,000 individuals m^{-2} in some cases (Cook *et al.,* 2013; Fariñas-Franco & Roberts, 2014). Other benefits provided by Horse Mussels include a stabilising effect on the seabed due to binding by byssal threads altering sea floor roughness, topography and sediment composition (OSPAR, 2009a).

The Native Oyster *Ostrea edulis* is a sessile, filter-feeding bivalve mollusc associated with highly productive estuarine and shallow coastal water habitats. It is typically found from the low intertidal zone to 10 m depth but occasionally as deep as 30 m (OSPAR, 2009c). Generally located in sheltered areas where clean, hard substrate is available to allow larval settlement, *O. edulis* rarely occur on muddy sediment as the presence of high quantities of silt in the water can block their digestive and respiratory tracts resulting in mortality (Pogoda *et al.,* 2011).

The distribution of *O. edulis* ranges from the Norwegian Sea and the coast of Norway south to the Atlantic coast of Morocco and is found on most European shores, including the Mediterranean and Black seas (OSPAR 2009c; Robert *et al.,* 2017). Naturally occurring populations of *O. edulis* are found in a number of locations on the northwest, west and southwest coasts of Ireland, such as Tralee Bay, Clew Bay, Blacksod Bay, Achill, Lough Swilly, Inner Galway Bay and Kilkieran Bay (OSPAR, 2009c).

Oysters can survive in a range of environmental parameters with a temperature tolerance of between 6°C and 30°C and a salinity tolerance between 29-34‰ (Pogoda *et al.,* 2011; Robert *et al.,* 2017). Multiple stressors (*e.g*. low salinity, low dissolved oxygen, pathogens) can cause high mortality in oysters as a result of physiological pressure. This is often correlated with the spawning period, due to the high energy expenditure at this time, leading to higher stress. High water temperatures in summer can also add to physiological pressures, increasing mortality rates. Pogoda *et al.* (2011) recorded that *O. edulis* is able to survive in conditions with Chlorophyll a levels between 3.7-21.2µg l^{-1}. Chlorophyll a is required for seaweeds to photosynthesise, however high volumes of chlorophyll a can indicate degraded water quality and can create anoxic conditions, which may lead to increased physiological stress and eventual mortality within oyster populations.

Information on *Limaria hians,* the Flame Shell*,* is limited, however species distribution is known to extend from south of the Canary Islands to the Lofoten islands in the North East Atlantic. The species is generally found in depths shallower than 100 m on a variety of coarse, gravelly sediments, with moderately strong tidal currents (0.25-1.5m s^1), in variable to full salinity areas (18-35‰) (Minchin, 1995; Hall-Spencer & Moore*,* 2000a; Trigg, 2009).

L. hians is an active suspension feeding bivalve, feeding on phytoplankton, benthic and epiphytic microalgae, bacteria and detritus. *L. hians* can grow to a maximum of 40 mm. Spawning is generally thought to occur later in the summer than other bivalves in Irish waters (typically July to September). *L. hians* are thought to be able to reproduce in their second year and, once settlement has commenced, populations are understood to have relatively high recoverability following any impacts (Minchin, 1995). However, reef survival seems to be highly dependent on recruitment, which if suboptimal, can lead to a rapid decline in the reef-forming population and associated community (Minchin, 1995).

Currently *L. hians* beds are not recognised as a ‘biogenic reef’ and are instead recognised as ‘semi-infaunal reef’. However, under the definition of ‘biogenic reefs’ proposed by Holt *et al.* (1998) the beds meet all specified criteria and, as such, recent studies (Hall-Spencer & Moore*,* 2000a; Trigg, 2009) have suggested that these beds be reclassified. *L. hians* is also recognised as a key structural species due to its vital architectural role in creating highly diverse habitats. Beds are created by a carpet of byssal threads of *L. hians* becoming interwoven with seaweeds, shell fragments, and the substrate, forming structures commonly referred to as nests. A study carried out on their associated community has found this habitat to be comparable to *M. modiolus* and *S. vermicularis* reefs in terms of richness and diversity, with 283 species of flora and fauna from an area of nest only 0.16 m^2 (Trigg, 2009).

Nests vary in size from just a few centimetres to over a metre in diameter and up to 20 cm thick, with the population of *L. hians* varying in some cases from 216 individuals per m^2 to >700 individuals per m^2 (Trigg & Moore, 2009). Nests form a reef structure and create a suitable substratum for attachment of many organisms, which otherwise would be unable to inhabit areas of mobile sediment. These nests increase biodiversity in the area, provide protection from predation, and act as nursery grounds for other marine species (Hall-Spencer & Moore*,* 2000a; Trigg, 2009). Hall-Spencer & Moore (2000a) recorded a total of 284 species associated with just six discrete nests in Loch Fyne, Scotland. Sessile, sedentary, and mobile species are often found in large numbers on, within, and underneath the nest. In shallow waters, many species of algae are associated with *L. hians,* including the Laminarians (kelp), which many organisms use for attachment and food.

It is understood that numbers of *Limaria hians* are in decline in many areas of Ireland and the UK, primarily due to fishing impacts (Hall-Spencer & Moore, 2000a; Trigg, 2009) which will be discussed in Section 4.

There are six main cold-water reef-forming coral species, all of which have global distributions, the most widespread of which is *Lophelia pertusa*. This species is capable of forming bush-like colonies, which can measure up to several metres in diameter (Freiwald *et al.,* 2004). It grows from single polyps to form colonies which merge to form large reefs several metres across, with a growth rate of about 6 mm per year (Wilson, 1979a & b; Hall-Spencer & Stehfest, 2008). Over time, continual growth can lead to the production of large reef structures dominated by *L. pertusa,* but also containing secondary Scleractinia corals including *Madrepora oculata, Oculina varicosa, Enallopsammia rostrata, Goniocorella dumosa,* and *Solenosmilia variabilis* (Davies *et al.,* 2008; Davies & Guinotte, 2011). The formation of such structures is acknowledged to have a positive ecological impact on the local habitat (Clark *et al.,* 2006) by providing a heterogeneous substrate for settlement and habitat provision.

The availability of hard substrate, including bedrock, rubble from old *Lophelia* colonies, or cobbles on the seabed is a prerequisite for settlement of coral larvae and the subsequent formation of colonies (OSPAR, 2009b; Clippele *et al.,* 2017). *Lophelia pertusa* appears to be negatively affected by high levels of sedimentation, due to smothering and blocking of feeding appendages as a result of their slow growth and sessile nature, and therefore areas with soft bottoms or high sediment loads are unlikely to be suitable (Davies & Guinotte, 2011). High nutrient supply and high currents also seem to be important factors in *L. pertusa* success (De Mol *et al.,* 2002). Therefore, environmental variables, such as availability of settling substrate, current speeds, food supply, and aragonite saturation state are thought to govern the distribution of reef-forming cold-water coral species (Naumann *et al.,* 2014).

Lophelia pertusa has a wide geographic distribution ranging from south of Brazil to the coast of Norway, with the majority of records occurring in the North East Atlantic. *L. pertusa* reefs are defined as biogenic structures, formed by *L. pertusa*, that alter sediment deposition and provide complex structural habitat (Davies *et al*., 2008). In the North East Atlantic these reefs are typically associated with water temperatures between 4-12°C, are subject to moderate current velocities (in the range of 0.5 knots) and occur in areas with dissolved oxygen levels between 6.0-6.2ml L^1 (Davies *et al.,* 2008). The species generally occurs from 200 m to 400 m depth but has also been recorded in shallower waters and to depths greater than 2000 m (Freiwald *et al.,* 2004; Roberts *et al.,* 2006; Hall-Spencer & Stehfast, 2008; OSPAR, 2009b). *L. pertusa* has been observed to tolerate salinities from as low as 32‰, in Scandinavian fjords, to at least 38‰, in the Ionian Sea (Freiwald *et al.,* 2004). The extent of live *L. pertusa* reef increases from south to north along the continental margins of Europe with one of the largest reefs reported to the south west of Ireland (De Mol *et al*., 2002; Hall-Spencer & Stehfast, 2008).

The distribution of Scleractinian corals has been shown to be highly related to the depth of the aragonite saturation horizon (ASH) (Clark *et al.,* 2006; Guinotte *et al.,* 2006), and most coral records are from waters supersaturated with aragonite Ω_{ARAG} >1 (Davies & Guinotte, 2011). In the northern Atlantic Ocean, in waters around the UK and Ireland, Ω_{ARAG} is at its greatest, ranging between Ω_{ARAG} 1.1 and 1.8 at 1000 m depth (Jiang *et al.,* 2015).

The conservation importance of *L. pertusa* reefs is increasingly recognised, not only because of their longevity and high biodiversity, but also because the delicate structure of *L. pertusa* makes these coral reefs particularly vulnerable to physical damage (Hall-Spencer & Stehfast, 2008; OSPAR, 2009b). Rates of annual growth for *L. pertusa* are estimated at 4-25 mm per year, therefore growth and recovery from disturbance is likely to be slow (Freiwald *et al.,* 2004).

The reef-forming coral *Madrepora oculata* is most often associated with *L. pertusa*, and some studies have shown that along the western European margins *M. oculata* reefs can be just as important in terms of spatial coverage and density as *L. pertusa*.

M. oculata is a Scleractinian coral (family Oculinidae) with a depth range of *c.* 50-2000 m (Freiwald *et al.,* 2004; Hansson *et al.,* 2009). *M. oculata* forms fan-shaped colonies 30-50 cm high (De Mol *et al.,* 2002), but these structures are weaker and more fragile than those made by *L. pertusa* (Hansson *et al.,* 2009). The northernmost record of *M. oculata* is from northern Norway and the southernmost from the subantarctic Drake Passage (Freiwald *et al.,* 2004). The distribution patterns of cold-water, corals including *M. oculata*, have been related to seawater temperature of 5-13°C and salinities of 35-38‰ (Naumann *et al.,* 2014).

On a global scale *M. oculata* occurrence, as with most Scleractinian corals, is predominantly associated with continental margins and seamounts, where there are often steep slopes or canyon flanks. *M. oculata* appears to display a higher growth rate and higher larval dispersal and settlement compared to *L. pertusa*. This allows for rapid colonisation of newly available areas which enables the species to be more prevalent in less stable areas (Arnaud-Haond *et al.,* 2017). However, little is known of the basic reproductive biology of habitat-forming cold-water corals (Freiwald *et al.,* 2004).

Although there is little information on the nutrition and food sources of cold-water corals, isotope analysis suggests that zooplankton and phytodetritus are the main food sources for *M. oculata* (Hansson *et al.,* 2009).

Table 2 Overview of the ecological and environmental requirements of biogenic reef habitat. Blank cells indicate that no information could be sourced for the species in question.

Species	Distribution	Preferred Substratum	Preferred Temperature Range	Depth Range	Preferred Salinity	Preferred Current Speed	References
Sabellaria spinulosa	NE Atlantic	Bedrock, rock, pebble, gravel, sand		0-40 m	30-35‰	1-3 kn	Holt *et al*., 1998 Connor *et al.,* 2004
Sabellaria alveolata	53ºS to 72ºN	Bedrock, rock, pebble, gravel, sand	5ºC-20ºC	0-20 m	30-35‰	1-3 kn	Holt *et al*., 1998 Connor *et al.,* 2004
Serpula vermicularis	Worldwide	Bedrock, boulders, stones, shells, man-made substrate	6ºC-15ºC	0-250 m	30-35‰	>1 kn	Minchin, 1987 Holt *et al*., 1998 Moore *et al.,* 1998 Connor *et al.,* 2004
Mytilus edulis	43ºN to 68ºN	Bedrock, rock, pebble, gravel, sand	-1ºC-29ºC	0-20 m	13-35‰	1-6 kn	Holt *et al*., 1998 Littorin & Gilek, 1999 Mainwaring *et al.,* 2014 Tyler-Walters, 2008
Modiolus modiolus	43ºN to 62ºN	Cobbles to muddy gravels	<23⁰C	5-80 m	27-41‰	1-3 kn	Holt *et al.,* 1998 Sanderson *et al.,* 2008 OSPAR, 2009a Hendrick *et al*. 2011
Ostrea edulis	28ºN to 68ºN	Rock, gravel, shells, mud	6ºC-30ºC	0-30 m	29-34‰		OSPAR, 2009c Pogoda *et al.,* 2011 Robert *et al.,* 2017
Limaria hians	28ºN to 68ºN	Bedrock, rock, pebble, gravel		0-100 m	18-35‰	>0.5 kn	Minchin, 1995 Hall-Spencer & Moore, 2000a Trigg, 2009
Lophelia pertusa	55°S to 70°N	Bedrock, coral rubble, cobbles	4ºC -12ºC	50-2000 m	32-38‰	>0.5 kn	Davies *et al*., 2008 Davies & Guinotte,2011 Freiwald *et al.,* 2004 OSPAR, 2009b

Species	**Distribution**	**Preferred Substratum**	**Preferred Temperature Range**	**Depth Range**	**Preferred Salinity**	**Preferred Current Speed**	**References**
Madrepora oculata	59°S to 69°N	Bedrock, canyons, seamounts steep slopes	5°C -13°C	5-2000 m	35-38‰	>0.5 kn	Freiwald *et al.*, 2004 Hansson *et al.*, 2009 Naumann *et al.*, 2014

3.2.1.1 Additional Reef-Forming Species

Other species are known to create ‘reef-like’ structures but have not been included within this project as they do not strictly meet the definition of ‘biogenic reef’. It is however worth noting some of these species which are discussed below.

Bryozoans, such as *Pentapora foliacea, Parasmittina trispinosa* and *Flustra foliacea* can form three-dimensional structures up to 100 cm in size. These large bryozoans, known as ‘frame-builders’ create structures which can alter the benthic habitat and provide habitat for a diverse range of species including other Bryozoans, Molluscs, Annelids, Arthropods, Cnidarians, Sponges, Echinoderms and macroalgae. They are known to occur within British waters with their distribution ranging between Norway and Antarctica (Wood *et al.,* 2012; Sheehan *et al*., 2013).

Musculus discors, a small bivalve, can form extensive beds on moderately exposed circalittoral rocks; the byssal threads used to fix it to the substratum can become woven into a nest or cage which completely encloses the adult mollusc. These nests can then incorporate macroalgae, such as *Fucus* spp. or *Laminaria* spp,. which provide camouflage for *M. discors* and additional habitat for other associated species. However, these aggregations do not usually form colonies more than one animal thick and do not form any significant raised reef area (Holt *et al.,* 1998; Tyler-Walters, 2001).

Lanice conchilega, the Sand Mason, is a well-known and widely distributed tube-dwelling polychaete bio-engineer capable of stabilising sediment. The tube aggregations constructed by this species can reach elevations of 45 cm and are known to positively influence the distribution and abundance of other infaunal species by increasing structural complexity, providing habitat and food for other species. However, there is uncertainty about the ‘reef’ status of this species as it is not known how stable these features are, and whether they alter habitats enough to qualify under the reef definition (Holt *et al*., 1998; Rabaut *et al.,* 2009).

Another polychaete which is able to form extensive reef is *Ficopomatus enigmaticus. F. enigmaticus* is an alien serpulid polychaete and was therefore not considered further in this report due to its non-native status. Reefs comprised of this species occur in scattered low salinity habitats within Ireland. Due to the brackish water habitats where these reefs occur few other species are found in association. The species does however undoubtedly form biogenic reef (Holt *et al.,* 1998).

The amphipod *Ampelisca* spp. can create large populations of semi-permanent tubes which can grow to create mat-like formations, typically in areas of sublittoral marine sand in moderately exposed to sheltered inlets. The tubes and mats that the amphipods create increase structural complexity, stabilise the sediment and prevent a shift in community towards one consisting entirely of deposit feeder’s, thereby increasing diversity in the local area (De-Bastos & Rayment, 2016).

Sea pens, such as *Eunicella verrucosa* and *Swiftia pallida*, have been suggested to create biogenic habitats, as their extension above the seafloor provides structural heterogeneity to the surrounding seafloor, providing areas for different species to attach and has been shown to act as a nursery habitat for fish species. However, there is no current evidence to support their role as a biogenic reef habitat (Ballion *et al.,* 2014).

Maërl are various species of coralline algae which live unattached to the seabed. These species can form extensive beds, generally in areas of sand and gravel, and act to increase habitat complexity. The beds can grow over long periods of time and as such often have high levels of benthic biodiversity and productivity, as well as acting as nursery areas for juvenile fish, crustaceans, and molluscs (OSPAR, 2010). Maërl is protected under Annex I habitats ‘large shallow inlets and bays’ and ‘sandbanks which are slightly covered by seawater at all times’. Although it is known to form ‘reef’ structures, maërl is not included in the definition of reef habitat and as such falls outside of the remit of this project.

3.2.2 The Physical, Chemical and Biological Requirements for the Formation of Geogenic Reef

Geogenic reefs are extremely variable, both in structure and in the communities they support. Communities supported can vary depending upon the rock type (*e.g*. chalk or limestone), the salinity (from estuarine to full salinity), and the current speed (<1 to >6 knots) (Connor *et al.,* 2004). Rocky reefs have a wide geographic spread and occur widely within Irish waters. Table 3 shows the range of environmental conditions in which rocky reef is known to occur.

Rocky reef is defined by its substratum rather than by a specific biological community; its range is therefore determined by physical and geological processes (JNCC, 2007). There are a wide range of topographical reef forms including vertical rock walls to horizontal ledges, sloping or flat bedrock, broken rock, boulder fields, and aggregations of cobbles. The only indicator of the possible occurrence of inshore reefs is the presence of intertidal rocky shores, but these may not be connected with subtidal areas; there is little comprehensive verified data available for offshore reefs.

The geographic spread and distribution of rock reef is unlikely to change as the range of rocky substratum is relatively stable and unlikely effected by localised pressures (JNCC, 2007). Despite this, the communities present on rocky shores are often physically unstable, due to a combination of physical disturbance, competition, grazing, predation and recruitment variation and as such the abundance of rocky shore species can be highly variable in time (JNCC, 2007). These varying environmental conditions and biological interactions also contribute to making geogenic habitats highly diverse (Hill *et al*., 1998). Natural fluctuations in community structure are poorly understood but are thought to be due to variations in the supply of planktonic propagules and survival following settlement, which are largely influenced by biological interactions and direct climatic effects (JNCC, 2007).

Table 3 Overview of the ecological and environmental requirements of geogenic reef habitat. Blank cells indicate that no information could be sourced for the species in question.

Reef Type	Distribution	Preferred Substratum	Temp. Range	Depth Range	Preferred Salinity	Preferred Current Speeds	References
Intertidal geogenic reef	Worldwide	Bedrock, boulders, cobbles, pebbles	-5°C - 30°C	Upper shore- 0 m	18-35‰	<1-6 kn	Hill *et al.,* 1998 Connor *et al.,* 2004
Infralittoral geogenic reef	Worldwide	Bedrock, boulders, cobbles, pebbles	0°C - 24°C	0- 20 m	18-35‰	<1-6 kn	Birkett *et al.*, 1998 Connor *et al.,* 2004
Subtidal geogenic reef	Worldwide	Bedrock, boulders	5°C- 20°C	20- 100 m	30-35‰	<1-6 kn	Connor *et al.,* 2004 Marine Institute Ireland, 2019

One of the characteristics of rocky reefs is the patchwork of different species and groups of species that occur and, depending on the location and depth of rocky substrate, different communities of geogenic reef can proliferate. These can be broadly categorised as intertidal, infralittoral and subtidal geogenic reef (Table 3). In the intertidal zone the predominant communities consist of larger macroalgal species which form the algal canopy on the shore and shorter algal species forming the turf communities below. Macroalgae provide a variety of resources for other species to colonise, by increasing the amount of space available to attach, and by providing shelter from wave action, desiccation and heat. They are also an important food source (Hill *et al.,* 1998).

Species in the intertidal zone are subject to a wide variety of environmental conditions, as communities are exposed to air as the tide recedes twice a day. Therefore, species have to be tolerant of highly fluctuating temperatures when they are exposed, and these temperatures can vary by 10-20°C in a single day (Hill *et al.,* 1998). Salinity can also be highly variable and can be influenced by inputs of freshwater (*e.g*. when it rains) and wave exposure can also determine the communities present (Hill *et al.,* 1998).

The infralittoral zone stretches from mean low water to a depth where 1% light reaches the seabed, this typically ranges from 0-20 m depth. The predominant communities in this area are dominated by kelp species. In Irish waters the main species include *Laminaria hyperborea*, *Laminaria saccharina*, *Laminaria digitata*, *Alaria esculenta* and *Saccorhiza polyschides*. Kelps do not tolerate a wide range of temperatures, from 0-24°C, and prefer full salinity conditions (30-35‰). Temperature is thought to be a major environmental factor limiting their range. Kelp communities are among the most ecologically diverse habitats. The three-dimensional structures they create provide additional habitats allowing a wide variety of different species and ecological interactions to occur (Birkett *et al.*, 1998).

Below the kelp, and down to about 30 m, red algae characterise the substratum, with very few brown algae. Below this the habitat becomes characterised by faunal species as light no longer penetrates to the seabed. This is where sublittoral reef occurs. In this area very few foliose or filamentous red algae occur, although encrusting red algae may be common. Although a range of species and growth forms can occur in subtidal rocky habitats the predominant structural species are generally sponges, hydroids, and bryozoans. Sponges and hydroids can provide substrata for attachment, refugia, and shelter for a variety of other species including amphipods, worms, and meiofauna. Sponges are thought to be vital components of subtidal reefs as they are filter feeders, capturing organic particles from prevailing currents and harbouring microsymbiont communities (van Soest *et al*., 2007). Environmental conditions in the sublittoral are generally much more stable than the intertidal zone, with temperature generally between 5°C and 17°C (Marine Institute Ireland, 2019), fully marine conditions (salinity 30-35‰) and less effect of wave exposure on communities.

3.3 Function of Reef Habitats in Irish Waters

If the appropriate physical, chemical, and biological requirements are met then the proliferation of reef habitat may occur. In order to further determine reef conservation status, the function and the services that reefs provide must also be assessed.

Reef habitat creates structures that reach into the water column from the seafloor creating important habitats for a variety of marine organisms by providing refuge from predation, competition, and both physical and chemical stresses. Reef habitats may also represent important food resources and critical nursery or spawning habitats, in addition to settlement surfaces for epibenthic organisms. Habitat structures that increase heterogeneity influence faunal abundance, species richness and species composition of invertebrate and fish communities and as such, emergent features that provide a structurally complex framework are critical to the functioning of many ecosystems (Rabaut *et al.,* 2009). Understanding ecosystem function, the delivery of ecosystem services, and the sensitivity of these seafloor structures may also support assessment and management of these habitats (Mainwaring *et al.,* 2014).

Rocky reefs are important ecological features and are well noted for their high levels of biodiversity, especially compared to surrounding sedimentary habitats. They include both bedrock outcrops and boulder or cobble fields or biogenic reef formed from accretions of animals. It has long been noted that such species, including beds of oysters, mussels, tubeworms and corals, known as reef-forming organisms, represent keystone species able to form complex structures, providing habitats and increasing biodiversity. Some can also have an important structural role in coastal areas. Reefs formed by living organisms are of scientific and conservation interest because of the stabilising effects they have on the physical environment and their ecological role. Biogenic reefs have been found to modify habitats, structure diversity and play a role in supporting food webs (Gibb *et al.,* 2014) further intensifying the need for effective management and conservation.

3.3.1 The Value and Function of Cold-Water Corals

Cold-water coral reefs, most commonly formed by *L. pertusa* and *M. oculata* are often described as ecosystem engineers, as they can form complex three-dimensional structures which alter local hydrodynamics and sediment deposition (Clark *et al.,* 2006; Clippele *et al.,* 2017). These complex structures offer a variety of microhabitats which serve as areas for protection, foraging, feeding, and spawning for other marine species including sponges, crustaceans, and echinoderms (Ballion *et al.,* 2014). They also provide hard substrates for colonisation by other sessile or encrusting organisms such anemones, bryozoans and other corals, and provide nursery areas for many fish species, including several which are commercially important (Clark *et al.,* 2006; Davies & Guinotte, 2011; Ballion *et al.,* 2014; Clippele *et al.,* 2017). *M. oculata* and *L. pertusa* have been found in association with over 100 taxa of deep-water megafauna (De Mol *et al.,* 2002).

Foley *et al.* (2010) stated that cold-water ecosystems are of significant ecological and economic value. They offer an extensive list of ecosystem services, all of which cannot be addressed in the current study. However, some of their services include acting as suppliers of goods and services for increased biodiversity, pharmaceutical compounds, cultural and scientific aspects, as a sink for CO_2 sequestration and for fisheries. Fish catches have been found to be higher in and around cold-water coral reefs (Clark *et al.,* 2006) further enhancing the need for their effective management.

3.3.2 The Value and Function of Bivalve Reefs

It is generally agreed that the most important biogenic reef-forming species in inshore British waters are *Sabellaria alveolata*, *S. spinulosa*, *Mytilus edulis*, *Modiolus modiolus* and *Serpula vermicularis* (Holt *et al.,* 1998). Bivalve reefs, (*Mytilus, Modiolus* and *Ostrea*), have been shown to provide a wide range of ecosystem services including shoreline protection, provisioning and influence on nutrient cycling. Additionally, their structured habitat can provide areas for juvenile fish species and nursery grounds for other marine organisms. As filter feeders, reef-forming bivalves filter particles from the water column which can act to increase water clarity (Newell, 2004; Ruesink *et al.,* 2005) which in turn may lead to an increase in biodiversity by improving growth conditions for other marine species. *M. edulis* is a filter feeder, capable of removing particles down to 2-3 µm with 80-100% efficiency and plays a large role in nutrient cycling. Additionally, *Mytilus* is particularly important both as a fishery, and as a source of food for birds and for many benthic predators (Holt *et al.,* 1998).

It is acknowledged that mussel beds provide additional substratum stability in rocky habitats, though investigations have demonstrated that the benefits provided by mussel reef formation are even greater in soft sediment regions. Studies have found that *M. edulis*, in soft bottom habitats, can alter the abundance of macrofauna compared to adjacent bare sediment by stabilising the substratum, modifying the sedimentary habitat and providing topographic complexity, allowing species to colonise (Commito *et al.,* 2005; Mainwaring *et al.,* 2014).

Ostrea edulis beds provide a similar role in the marine environment which has led to it being considered a keystone species (OSPAR, 2009c; Tully & Clarke, 2012). The economic value of the ecosystem services derived from unharvested oyster reefs in North America was recently estimated to be as high as $99,000/ha/year (Grabowski *et al.,* 2012) though the economic value in Irish waters is currently unknown. The primary service provided by oyster reefs is the provision of a cryptic habitat, which allows for the settlement of other species. This in turn provides food for juvenile fish and economically important fish stocks, as well as providing areas for foraging, refuge and nursery grounds (OSPAR, 2009c; Grabowski *et al.,* 2012). In addition to this, oyster reefs are able to counteract increases in anthropogenic nitrogen in the water column by filtering large quantities of water, thus promoting denitrification, and simultaneously reducing pollution. The removal of nitrogen from the water column can lead to a decrease in phytoplankton and algae by removing their primary nutrient source. As such there are fewer particles in the water column competing for light, which in turn can increase light attenuation in the water, benefiting seagrass and salt marsh habitats, areas that have long been recognised as critical for many fish species. It also leads to the deposition of biodeposits, through the channelling of nutrients from the water column to faeces and pseudofaeces, providing continuous fertilisation to benthic sediments (Grabowski *et al.,* 2012; Green *et al.,* 2017).

Finally, oyster reefs can act to reduce coastal erosion by functioning as natural breakwaters, by interacting with the tide, attenuating wave energy which consequently stabilises surrounding sediment. As such, the placement of oyster beds has been proposed as a potential method for shoreline protection. The rate of growth of oyster reefs is far greater than predicted sea level; reefs could serve as natural protection against shoreline erosion, intertidal habitat loss, and property damage along many shorelines (Grabowski *et al.,* 2012).

Limaria hians is also recognised as a keystone species able to form complex, species rich habitats. Other services include stabilisation of mobile sediment, provision of suitable substrata for attachment of sessile organisms and the accumulation of faeces and pseudofaeces which are used as a source of food by many organisms (Holt *et al*., 1998).

3.3.3 The Value and Function of Polychaete Reefs

As with other reef-forming species, polychaete worm reefs often support a diverse flora and fauna and have been shown to play an important role in increasing stability and structural composition of the seabed and are important feeding grounds for many marine species (Culloty *et al.,* 2010; Sanders *et al.,* 2016).

Through the construction of physical structures *Sabellaria* spp. provide shelter from predation for other species. In addition, the structures they create modify the hydrodynamic flow regime near the sea floor. This plays an important role in the ecosystem by altering water flow, reducing wave energy and has potentially significant ecological effects on sedimentation patterns, food availability, larval and/or juvenile recruitment, growth, and survival (Naylor & Viles, 2000; Dubois *et al.,* 2006; Braeckman *et al*., 2014).

Sabellaria alveolata and *Sabellaria spinulosa* are known as autogenic ecosystem engineers, as they change the environment via the physical structures they create. In areas where both *Sabellaria alveolata* and *Sabellaria spinulosa* are present, species richness of the associated infauna is much higher than is seen in the surrounding sediments, as their reef structures add structural complexity and high levels of biodiversity to the otherwise low relief, low diversity sedimentary habitats (Dubois *et al.,* 2002; Braeckman *et al*., 2014). The structurally complex reef provides crevices and breeding grounds for an array of marine benthic organisms (Schimmenti *et al.,* 2015). These reefs also play important roles in the ecosystem by altering water flow, and by filtering large volumes of water (Naylor & Viles, 2000; Dubois *et al.,* 2006).

Serpula vermicularis is also considered an ecosystem engineer and can play a significant role in the ecology of coastal ecosystems by altering the physical environment through the construction of reef structures, modifying water flow, trapping sediment and by increasing habitat complexity (Hughes *et al.,* 2008). The production of reef provides additional hard substrata to the seabed, allowing other organisms to attach, leading to increased biodiversity (Sanfilippo *et al.,* 2013).

3.3.4 The Value and Function of Geogenic Reef

Geogenic reefs are defined by the presence of rocky substrata including bedrock or stable boulders and cobbles. The presence of this hard substratum functions to provide an area on which many species of algae and sessile fauna can attach and colonise and as such these habitats are associated which a higher diversity than sedimentary habitats. The attachment of large algae in these areas can further provide habitat for the subsequent colonisation of other species such as more delicate red seaweeds, sponges and tunicates. Shade provided by the larger canopy seaweeds also provides shelter for a wealth of mobile fauna such as the mollusc *Littorina* spp., *Patella* spp., the crustacean *Carcinus maenas*, and the echinoderm *Asterias rubens* (Irving, 2009).

In the infralittoral zone, kelp forests are some of the most ecologically dynamic and biologically diverse habitats, with a wide variety of different species assemblages (Birkett *et al*., 1998). Kelp communities produce a three-dimensional structure which can provide habitat for other marine species by increasing habitat complexity and providing substrata for other species to attach and settle. Kelp themselves also provide a food source for other organisms and provide shelter and nursery grounds for a wide range of taxa including species of commercial importance such as lobster, crawfish, crabs, and octopus (Birkett *et al.,* 1998). Over 1500 benthic faunal species have been reported from kelp biotopes in European waters.

Kelp beds have considerable conservation value as they are the major primary producers in temperate marine coastal habitats. Within the coastal infralittoral zone kelps produce nearly 75% of the net carbon fixed annually on a shoreline. Kelp detritus (particulate organic matter) and dissolved organic matter are exported from kelp beds and support deeper water ecosystems and soft bottom habitats (Birkett *et al.,* 1998).

In the rocky subtidal communities, the range of growth forms of sponge and hydroid communities can provide structural complexity to the habitat and can also provide hard substrata for attachment, refugia, and shelter. Sponge and hydroid communities can provide enhanced food supply in feeding currents and act as potential food sources themselves. Communities that occur in more sheltered conditions are likely to accumulate silt on upward facing surfaces which may further attract small species such as amphipods, worms and meiofauna (Readman & Hiscock*,* 2016).

The rocky subtidal zone is an important nursery area for many commercially important species of fish including herring, cod and hake. These species can migrate into the intertidal zone, feeding as the tide rises and are important predators of rocky shore species. Corkwing Wrasse *Symphodus melops*, which are important to the aquaculture industry as a cleaner species, also rely heavily on the intertidal zone and juveniles are commonly found in rock pools (Hill *et al.,* 1998). Rocky intertidal shores also provide an important habitat for shore birds which feed under the macroalgal canopy and on the invertebrates attracted to seaweed on the strandline (Hill *et al.,* 1998)

Several rocky shore species are commercially exploited in Ireland and the UK. The main commercial species are seaweeds (Knotted Wrack *Ascophyllum nodosum* and kelps *Laminaria* spp), winkles (*Littorina littorea*), mussels (*Mytilus edulis*) and edible crabs (*Cancer pagurus*). Kelp species are harvested for food, fertiliser and for the chemical industries, and the demand for the chemicals is increasing (Birkett *et al.* 1998).

3.4 The Biodiversity of Reef and Associated Faunal Assemblages

One of the primary functions of reef habitat is the increase in biodiversity of the species living on, within, and in association with the habitat. Assessing the species which are associated with reef structures is an essential part of determining habitat conservation status. It is therefore essential to define which species are considered ‘typical’ of the habitat.

While there is no universal definition of faunal associates or associated species, the terms typically refer to species that find living space, shelter or food in or around a given substrate, habitat or species (Ballion *et al.,* 2014). In the current study, associated fauna were determined as species found living within the habitat, or in close proximity to reef.

An initial review of EUNIS biotope descriptions for all habitats assessed as Annex I reef (Connor *et al*., 2004) and all taxa associated with the project biotopes yielded a list of 283 species for geogenic reef and 2175 species for biogenic reef. In tandem with the review of biotope descriptions, a literature search was conducted to highlight other key species associated with biogenic and geogenic habitats.

3.4.1 The Biodiversity of Geogenic Reef

Due to the geographical range in which geogenic reef occurs, from the intertidal zone to the deep subtidal zone, a wide variety of associated habitats and species exists. Intertidal and shallow subtidal geogenic reef is often associated with red and brown macroalgal dominated communities, as it provides a steadfast surface for growth. Over 1500 benthic faunal species have been recorded to date from kelp biotopes within Irish and UK waters (Birkett *et al.*, 1998).

Deeper into the subtidal zone, where algae can no longer proliferate due to lack of light, geogenic reef communities often become dominated by invertebrate species. These assemblages commonly include sponges, cnidarians, polychaetes, crustaceans, molluscs and echinoderms.

Reef habitats in the intertidal and infralittoral are commonly associated with macroalgae species. Large brown macroalgae often dominate the Irish shoreline, with species such as *Fucus spiralis, Fucus vesiculosus* and *Fucus serratus* and the kelp species *Laminaria digitata, Laminaria hyperborea* and *Saccharina latissima* frequently present (Birkett *et al.*, 1998). Underneath the canopy of these large algal species, smaller red seaweeds such as *Corallina officinalis, Palmaria palmata, Rhodothamniella floridula, Porphyra* spp*., Delesseria* spp*., Osmundea pinnatifida* and *Plocamium cartilagineum* often occur alongside calcareous encrusting seaweeds such as Corallinaceae and *Lithothamnion glaciale*. In contrast to these submerged regions of the intertidal zone, the higher reaches of the shore are more typically dominated by the presence of lichens such as *Caloplaca* spp*., Verrucaria maura* and *Xanthoria parietina* (Connor *et al.,* 2004; NPWS, 2013a). Green seaweeds which most commonly occur include *Enteromorpha* spp., *Codium* spp., *Cladophora* spp., *Ulva intestinalis* and *Ulva lactuca* (Connor *et al.,* 2004). The presence of many of these species is determined by the availability of hard substrate, such as bedrock or boulders, which allows them to attach and colonise. The presence of reef habitat is therefore essential for the proliferation of many of the species discussed above (JNCC, 2007).

Sessile fauna often require the presence of a solid substrate for colonisation and therefore these species are often found associated with areas of geogenic reef. Invertebrate species commonly seen in these habitats include sponges (*Halichondria panicea, Cliona celata, Pachymatisma johnstonia),* cnidarians (*Anemonia viridis, Actinia equina, Sagartia elegans, Alcyonium digitatum)*, tunicates (*Ascidia mentula, Ciona intestinalis, Dendrodoa grossularia*), bryozoans (*Alcyonium digitatum, Flustra foliacea*), polycheates (*Sabellaria alveolata, Pomatoceros triqueter*), crustaceans (*Balanus* spp*., Semibalanus balanoides),* and molluscs *(Mytilus edulis, Modiolus modiolus)* (Connor *et al.,* 2004; NPWS, 2013a).

Mobile invertebrate species often associated with geogenic reef include crustaceans (*e.g*. *Carcinus maenas, Necora puber, Pagurus bernhardus, Galathea* spp.), molluscs (*Gibbula* spp*., Littorina* spp*., Nucella lapillus, Patella* spp.), and echinoderms (*Echinus esculentus, Marthasterias glacialis, Holothuria forskali, Aslia lefevrei*) (NPWS, 2013a). Fish species commonly associated with shallow subtidal reefs include *Pholis gunnellus, Lotidae* spp., *Nerophis lumbriciformis, Pollachius* spp., *Conger conger*, and *Labridae* spp. (NPWS, 2013a). Although many of these species can inhabit a range of habitats, their abundances are often higher in areas of geogenic reef. This is due to the increased structural complexity of the habitats and areas of shade, refuge, feeding and nursery grounds provided by the mosaic of species present (Wildlife Trust, 2017).

3.4.2 The Biodiversity of Biogenic Reef

Biogenic reefs provide an ecosystem function in the form of habitat provision for benthic fauna. Structurally complex habitats created by biogenic reefs can have up to three times the biological diversity and greater species richness of macroinvertebrates than surrounding soft sediments (Sheehan *et al.*, 2015). There is a growing inventory of species that are known to associate with these reefs in the OSPAR area, and the current tally stands at over 1,300 species (OSPAR, 2009b).

The macroalgal assemblages associated with intertidal *Sabellaria* spp. are generally dominated by brown seaweeds such as *Fucus vesiculosus*, *F. serratus* and red seaweeds such as *Ceramium* spp., *Laurencia* spp., *Palmaria palmata*, *Corallina elongata*, and *Lomentaria* spp. Green algae including *Ulva lactuca*, and *Enteromorpha* spp. are also seen among the tubes (Holt *et al.,* 1998). Red seaweeds, *e.g. Ceramium* spp. and *Osmundea* spp., are also associated with other biogenic reef species such as *Ostrea edulis* and *Mytilus edulis* in the intertidal and shallow subtidal zone, when shallow enough so sufficient light can penetrate to allow photosynthesis, however they do not tend to extend into deeper waters (Irving, 2009).

In temperate coral reefs, characteristic species include hard corals, such as *Oculina varicosa, Enallopsammia rostrata, Goniocorella dumosa, Desmophyllum dianthus,* and *Solenosmilia variabilis* (OSPAR, 2009c; Davies & Guinotte, 2011; NPWS, 2013a). Coral reefs commonly harbour abundant sessile suspension feeders and a multitude of grazing, scavenging and predatory invertebrates.

Some of the key species associated with *S. alveolata* reefs are sessile epifauna, including the barnacle species *Chthamalus montagui*, *C. stellatus* and *Semibalanus balanoides* and the Blue Mussel *Mytilus edulis* (Holt *et al.,* 1998).

The interior of *L. hians* nests are inhabited by a number of species, such as the polychaete *Flabelligera affinis* and the bivalve *Mysella bidentata,* which probably feed on the faeces of *L. hians (*Trigg, 2009). Other infaunal bivalves such as *Mya truncata* and *Dosinia exoleta* are also commonly seen in association with *L. hians* (Trigg, 2009). Due to the complex structure of the beds, the subsequent attachment by kelp provides additional primary production, by way of detritus and dissolved organic matter supplying food for grazers such as amphipods, isopods and gastropods (Trigg, 2009). Trigg *et al*. (2011) also noted the polychaete *Lysilla nivea* in association with *L. hians* beds off the west coast of Scotland. This is of particular interest as *L. nivea*, originally described from Madeira, has only recently been found in UK waters within the southern Irish Sea.

The fauna associated with *M. edulis* beds can be variable, depending on the substrate *Mytilus* beds have attached to. Beds generally support an assemblage of suspension feeders including barnacles *(Semibalanus balanoides, Austrominius modestus* or *Balanus crenatus),* polychaetes, and tunicates. In more sedimentary areas, the Blow Lugworm *Arenicola marina*, the Sand Mason *Lanice conchilega,* and the Common Cockle *Cerastoderma edule* are common, along with other infaunal species (Mainwaring *et al.,* 2014).

Polydora ciliata, a burrowing worm and *Mytilicola intestinalis,* a parasitic copepod, are also widely prevalent on *M. edulis* reefs though both often have a detrimental effect on populations; *P. ciliata* by burrowing into the shells and weakening them rendering them more susceptible to predation, and *M. intestinalis,* found in the gut and stomach, has been shown to cause obstruction and damage to the intestine leading to mass mortalities of mussels (Robledo *et al.,* 1994; Holt *et al.,* 1998).

Sessile fauna recorded in association with *S. vermicularis* included other serpulids, such as *Pomatoceros triqueter,* spirorbids and other tube worms, numerous encrusting bryozoans, the anemone *Metridium senile*, and numerous bivalves such as *Monia patelliformis*, *Modiolus modiolus*, *Chlamys distorta*, *C. varia,* and *Aequipecten opercularis* (Holt *et al.,* 1998). The tunicate *Pyura microcosmus* is largely limited to this habitat. The Boring Sponge *Cliona celata* is also largely linked to this habitat, however as the colony ages *C. celata* can significantly weaken the reef structure (Holt *et al.,* 1998).

Cold-water reefs are presumed to act as nursery grounds for commercial fish species such as Redfish *Sebastes* spp., and European Hake *Merluccius merluccius*, and provide hunting areas for demersal predators such as Common Monkfish *Lophius piscatorius*, Atlantic Cod *Gadus morhua*, Common Ling *Molva molva*, Saithe *Pollachius virens*, and Tusk *Brosme brosme* (Husebø *et al.,* 2002; Costello *et al.,* 2005; Söffker *et al.,* 2011). Aggregations of Orange Roughy *Hoplostethus atlanticus* are also found in cold-water coral environments (Armstrong *et al.,* 2014). Coral reefs also support a multitude of invertebrates; the main associates include crustaceans (*Pandalus* spp., *Munida* spp.), molluscs (*e.g. Acesta excavate),* echinoderms (*e.g. Cidaris* spp., *Gorgonocephalus* spp.), cnidarians (*Alcyonium* spp.), sponges, and polychaetes (JNCC, 2008).

The crabs *Pilumnus hirtellus, Porcellana platycheles,* and *Lophozozymus incisus* are seen commonly inhabiting *S. alveolata* and *S. spinulosa* reefs. The high proportion of both females and berried females, especially of *L. incises* associated with *Sabellaria,* suggests that these colonies provide shelter for ovigerous females (Almaça, 1990). Plaice *Pleuronectes platessa,* and Dover Sole *Solea solea*, are common fish species seen among this habitat, both of which are seen to feed on *Sabellaria* (Holt *et al.,* 1998). Other key species associated with *S. alveolata* reefs are limpets, including *Patella vulgata*, *P. depressa,* and *P. aspera*, and the Dogwhelk *Nucella lapillus* (Holt *et al.,* 1998).

A study by Pearce *et al.* (2011) found 16 key fish species associated with *Sabellaria spinulosa* reef in the North Sea; the Butterfish *Pholis gunnellus*, Dover Sole *Solea solea*, Dab *Limanda limanda,* Northern Rockling *Ciliata septentrionalis*, Pogge *Agonus cataphractus*, Dragonet *Callionymus lyra*, Lesser Weever *Echiichthys vipera*, Bull Rout *Myoxocephalus scorpius*, Whiting *Merlangius merlangus*, the Sea Scorpion *Taurulus bubalis*, Greater Sand Eel *Hyperoplus lanceolatus,* Poor Cod *Trisopterus minutus*, Bib *Trisopterus luscus,* Plaice *Pleuronectes platessa,* Dogfish *Scyliorhinus canicula,* and Flounder *Platichthys flesus*, the majority of which are commercially valuable species. Of these species, nine were seen to feed directly on *Sabellaria spinulosa,* with it being the main component of the diet in Dover Sole, Dab, Dragonet, and Plaice. The commercially valuable Pink Shrimp *Pandalus montagui* also seems to have a strong association with *S. spinulosa* reefs (Holt *et al*., 1998). The flatfish Plaice, Flounder, and Dab are also commonly associated with *M. edulis* beds (Holt *et al.,* 1998).

The high abundance of food available in bivalve beds attracts many mobile predators such as the crabs *Cancer pagurus* and *Necora puber,* and the starfish *Asterias rubens* and *Marthasterias glacialis* which are known to predate on *M. edulis* and *L. hians.* Clumps of hydroids on *L. hians* beds attract large numbers of juvenile fish such as Atlantic cod *Gadus morhua,* Saithe *Pollachius virens*, and other commercially important species such as King Scallop *Pecten maximus,* and Queen Scallop *Aequipecten opercularis* have been associated with these beds (Trigg, 2009). Key scallop species *(Pecten maximus*, *Aequipecten opercularis* and *Chlamys islandica*) are also seen in association with *Modiolus modiolus* (OSPAR, 2009a).

Mussel beds act as a source of food for many intertidal bird species. Some of the species more commonly associated with the beds include Oystercatchers *Haematopus ostralegus*, Eider Ducks *Somateria mollissima*, Knots *Calidris canutus*, Sandpipers, Herring Gulls *Larus argentatus*, Scoters *Melanitta* spp., Turnstones *Arenaria interpres*, Curlews *Numenius arquata*, and Redshanks *Tringa tetanus* (Holt *et al.,* 1998).

Mobile predators which have been recorded feeding on *Serpula vermicularis* reefs include the urchins *Echinus esculentus* and *Psammechinus miliaris*, the brittle star *Ophiothrix fragilis,* and the starfish *Asterias rubens*. The urchin *P. miliaris* is abundant in areas of *Serpula* reef and has been recorded feeding on *S. vermicularis* tubes in Ireland. It is therefore considered a potentially important bioeroder in this serpulid reef habitat (Hughes, 2011).

The wrasses *Ctenolabrus rupestris* and *Crenilabrus melops* have been seen frequently biting open serpulid tubes and extracting the worms. *Pholis gunnellus, Necora puber, Cancer Pagurus,* and the squat lobster *Galathea squamifera* have also been observed feeding on *S. vermicularis* (Holt *et al.,* 1998; Poloczanska *et al.,* 2004). Poloczanska *et al.* (2004) also recorded the European Shag *Phalacrocorax aristotelis,* swimming and feeding on fish found around the reefs.

3.4.3 Summary of the Ecology and Biodiversity of Biogenic and Geogenic Reefs

Reef habitats can proliferate across a wide range of environmental gradients; however, each reef type requires certain environmental conditions, and these exact conditions determine which reef species are able to survive in which areas. Tables 2 and 3 provide an overview of the ecological requirements of each reef habitat; understanding these requirements is essential for determining reef location and for future conservation of reef habitats.

Geogenic reefs are defined by the substratum rather than by a specific biological community, and as such the range of these habitats is therefore determined by physical and geological processes (JNCC, 2007). As a result, rocky reefs are extremely variable, both in structure and in the communities they support.

Biogenic reefs are defined by the presence of a structure created by animals themselves. Many of these reef-forming species form extremely variable community types, with obvious gradation between non-reef and reef biotopes (JNCC, 2007). Predicting their exact range is difficult, however knowing the environmental conditions under which they proliferate aids this.

Overall, reef habitats and biogenic reef species provide a range of positive effects for the surrounding environment. Typically, they provide an increase in structural complexity and a cryptic habitat which allows for the settlement of other species, in turn providing food for juvenile fish and economically important fish stocks, as well as providing areas for foraging, refuge and nursery grounds (OSPAR, 2009c; Grabowski *et al.,* 2012). In addition to this, bivalve reefs are able to maintain and regulate habitats, to a certain extent, and in some cases, they can counteract increases in anthropogenic nitrogen in the water column by filtering large quantities of water, thus promoting denitrification and simultaneous reduction in pollution.

Due to the wide range of functions that reefs perform there are a large number of flora and fauna associated with these habitats, some of which are regarded as commercially important species *e.g*. Dover Sole *Solea solea*, Dab *Limanda limanda*, and Plaice *Pleuronectes platessa*. The literature search revealed 2307 species known to exist in proximity to reef habitats, including a wide range of taxa such as molluscs, crustaceans, echinoderms and chordates. Without the presence of reef habitat many of these species would not be found on the surrounding seabed (JNCC, 2007).

3.4.4 Knowledge Gaps

Although policy makers recognise the importance of biogenic reefs and understand that successful protection measures require information on the structure, function and ecological requirements of these habitats, as well as on the goods and services that they provide, there are several knowledge gaps in the understanding of biogenic and geogenic reefs. For example, the literature review revealed that information was more readily available when looking at *Lophelia pertusa* as a cold-water coral species than for *Madrepora oculata,* despite the literature highlighting their equal role in reef building in North Atlantic waters. Additionally, due to the infancy of cold-water coral research, it is probable that not all Irish cold-water corals have been successfully located, leading to concerns that these habitats may be destroyed by activities such as fishing before they have been recorded. There have also been few publications on the economic value of reefs with regards the goods and services they provide (Foley *et al.,* 2010; Glenn *et al*., 2010).

Knowledge of biogenic reef location and distribution is generally lacking for most reef-forming species; this is mainly as a result of the patchy distribution of biogenic habitats and partly due to uncertainty as to whether records refer to individuals or beds, and as such detailed up-to-date information on distribution is absent over significant parts of the species range. Without such information, providing accurate estimates of the area covered by reef habitat is challenging, which presents significant difficulties when devising strategies to provide appropriate protection and monitor reef habitats.

Research focussing on *Limaria hians* is also in its infancy, especially when focussing on its role as a reef-forming species. Despite research on the characteristics of *L. hians* and its associated community, there are still substantial gaps in the knowledge base for *L. hians* ecology and biology (Hall-Spencer & Moore, 2000a; Trigg, 2009).

There is also very little information of the ecology and dynamics of *Serpula vermicularis* reefs in Northern Europe. Although they are known to support a diverse associated fauna, data on growth rates, recruitment and environmental tolerances are generally lacking (Hughes *et al*., 2008).

Further knowledge of biogenic and geogenic habitats will enable decision makers to focus management initiatives on those which will have the greatest potential to protect these habitats but also uphold commercial interests in the marine environment.

3.5 Indicators to Aid in Evaluating the Structure and Functions of Reef

Using information gathered during the literature review phase of this project, environmental parameters important for regulating the establishment of reef habitats have been identified, with the aim of determining potential indicators which may aid in assessing reef distribution.

An indicator is a measurable factor that can be quantified and used to monitor the status of an ecosystem. Indicators can be related to any aspect of the marine environment, but good indicators are typically straight forward and easy to comprehend, sensitive to changes in the environment, accurately measurable and provide crucial information about the target habitat. Indicators may include species, communities, or other biological properties, as well as physical or chemical properties of the environment (Noon & McKelvey, 2006).

Potential indicators that may aid in evaluating the structure and functions of coastal and subtidal reef habitat have been identified in Table 4 and Table 5. These have been separated into physical, chemical, and biological categories. A short rationale is presented for each potential indicator. The information presented in Table 4 and Table 5 is based on expert judgement. It should be noted that at this stage, no consideration has been given to the monitoring methodology or practicality of including these features in a monitoring programme.

There may be other monitoring criteria which are important when considering reef habitat structure and functions; however, those indicators presented in Tables 4 and 5 are considered the key components identified by this project.

Table 4 Potential physical indicators for monitoring reef habitat structure and functions.

Indicator	Rationale
Habitat elevation	The Habitats Directive indicates that a biogenic concretion should 'arise from the sea-floor' if it is to be considered a reef and therefore habitat elevation is essential in defining the structure of reef habitat. The growth form of reef and its elevation above the seafloor can determine the function of the habitat as increased elevation will increase structural complexity and thereby increase associated diversity. It will also modify the environment, potentially altering water flow and reducing wave energy (Dubois *et al.,* 2006).
Habitat patchiness	The patchiness of reef habitat is likely to determine its structure and functions. More coherent, joined reefs provide increased habitat complexity, increasing biodiversity and abundance of associated species. Increased patchiness can also increase reef susceptibility to disturbance, which will further affect the structure of the habitat.
Habitat extent	Spatial extent is an important physical characteristic of a reef. A more extensive colony has greater conservation significance than a smaller one due to the increased services that it can provide. For example, nursery grounds, food provisioning, shelter and increased habitat complexity. Increased habitat extent also increases reef recoverability and habitat tolerance to disturbance due to higher levels of habitat stability (Hendrick & Foster-Smith, 2006). Irving (2009) suggests a minimum habitat extent of 25 m^2 to classify as reef habitat.
Substrate type	The availability of hard substratum has been shown to be an important factor influencing the proliferation of reef habitat as it provides essential space for propagules to settle, grow and coalesce into extensive areas of reef (Forde *et al., In prep.*). Therefore, the presence of bedrock, boulders and cobble substrates are key in determining the structure and functions of reef habitat. Irving (2009) suggest that to classify as stony reef, there must be a greater than 10% coverage of cobbles (>64 mm).
Wave Exposure/ Water Currents	Wave exposure and water currents are dominant factors controlling the distribution of flora and fauna in the marine environment (Little & Kitching, 1996; Norderhaug & Christie, 2011). Wave exposure is a key driver of intertidal and infralittoral reef habitats, and increased wave action can cause significant changes in macrobenthic species richness, abundance and biomass, resulting in significant changes to faunal diversity over time. A change in water flow can have a detrimental effect on reef populations by affecting larval dispersion, thereby reducing recruitment to a population or by altering the delivery of nutrients or reef-building materials to an area (Hendrick *et al.,* 2011). This is likely to have a high impact on cold-water corals, which rely on currents to bring food and nutrients or to *Sabellaria* spp. which require sand and shell fragments in order to build their reef-structures.
Temperature change	Temperature is a key driver in sublittoral and littoral rock habitats, determining the geographical patterns of distributions of marine species (Hiscock *et al.,* 2004). The distribution of some reef species is determined by water temperature, for example cold-water corals are limited to waters between 4-12°C. Increasing temperatures can therefore alter the distribution of species in the marine environment. Generally, warm-water species are likely to replace cold-water species, with cold-water species moving to more northerly latitudes or greater depths (Hill *et al.,* 1998; JNCC, 2007). For example *Modiolus modiolus*, a northern species, is likely to retract its range with rising sea temperatures.
Light attenuation	Light attenuation is predominantly dependent on water turbidity and depth, although it is also influenced by the presence of algal canopies in rock habitats. Light attenuation will predominantly impact intertidal and infralittoral reef habitats so cannot be used as an indicator for subtidal reef. Any change in light attenuation may impact primary production and food sources for fauna, as decreases in light attenuation will lead to less macroalgae and therefore a decrease in habitat complexity, reducing species diversity of the habitat (Birkett *et al.,* 1998)

Table 5. Potential biological indicators for monitoring reef habitat structure and functions.

Habitat Component	**Rationale**
Species abundance/Habitat extent	Physical monitoring of abundance, cover and/or biomass of reef species or habitats will show that there has been a positive, negative or no change in extent of the ecosystem component of interest. For reef-forming species size of reef, reef connectedness, height of reef and proportion of live vs. dead reef can also ensure the natural distribution, extent, and character of habitats are maintained. Linking measurements of specific species with known sensitivities to various aspects of physical loss, *e.g*. smothering, physical damage may assist in determining a causal factor to any reef decline (Langmead *et al.,* 2008).
Macroalgae	Macroalgae form a key ecological group in intertidal and infralittoral geogenic reef habitats, however they cannot be used as indicators of biogenic or subtidal geogenic reef. A lot of macroalgal species are highly seasonal and produce numerous important output processes and ecosystem functions, such as shade, shelter and substrate for attachment for other species, changes in which have the potential to have large impacts on other organisms within the habitat.
Abundance of non-native species	The geographic distribution, relative abundance and relative number of invasive rocky reef species, both invertebrates and macroalgae, will provide information on whether invasive species in a community increase, decrease, or have no effect on the native biodiversity of a community. As well as having direct impacts on native community composition and the potential to alter ecosystem function and services, non-native species can also be used to indicate levels of disturbance or change in a habitat (Langmead *et al.,* 2008). Invasive species include (Burrows *et al.,* 2014); • *Sargassum muticum* – Rapid growth to a large size which can shade species on the shore preventing growth. • *Magallana gigas* – can overgrow species such as *Mytilus* and *Sabellaria* and can degrade reef structure. • *Crepidula fornicata* – Outcompetes reef species, decreases reef structural complexity and degrades habitat, preventing settlement of larvae. • *Corella eumyota* – rapidly colonises substrates preventing settlement of reef species • *Undaria pinnatifida* – Competes with native kelp species in particular *Saccorhiza polychides.*
Recruitment	Recruitment is a key biological factor which affects structure and functions of reef habitat due to the supply of new larvae for continued survival of reef or for recovery of reef following disturbance. Reduction of recruitment of reef species could lead to reef mortality and therefore loss of reef function in the habitat. This will lead to a lower abundance and diversity of associated reef fauna.

4 Potential Pressures, Threats and Conservation Measures

This part of this project aims to identify the pressures and threats facing intertidal and subtidal reef habitats and to assess any conservation measures which are being applied to protect them. Any records of damage to geogenic or biogenic reef have been collated during the literature review, in order to highlight areas of reef, within Irish waters, which may be susceptible to environmental degradation or change.

Most of the research on pressures and threats focuses on the most common reef-forming species and those with commercial benefit, such as *Mytilus edulis,* and therefore many of the conservation measures focus on those more researched reef habitats. As there is comparatively little information on species such as *Limaria hians* and other rarer reef forms, there are also fewer conservation measures in place to protect these habitats.

4.1 Physical Damage or Loss

4.1.1 Fishing

Fishing is the most widespread and damaging activity in a variety of biogenic reef types (Holt *et al.,* 1998). A summary of the impacts of various types of fishing gear on reef habitats in Irish waters is shown in Table 6. Figure 7 shows the locations of fishing activities within Irish waters and shows where these activities may overlap with reef habitat.

The principle threat to cold-water coral reefs is physical damage by fishing gear (Hall-Spencer & Stehfest, 2008; 2009). In particular, bottom trawling has been identified as probably the most severe immediate threat facing cold-water corals (Davies *et al.,* 2008), but damage from gill nets, long-lining gear and ground-fishing gear can also devastate coral colonies (Clark *et al*., 2006). Fishing gear can become entangled on reefs, causing direct physical harm to both the reef and its associated epibenthic community (HELCOM, 2013). This can potentially cause a reduction in the structural complexity of coral grounds which reduces species diversity (Freiwald *et al*., 2004). Fishing has a further impact on the surrounding marine ecosystem as ecosystem diversity is threatened and the system's resilience is weakened (Foley *et al*., 2010).

In recent decades, trawling, gillnetting, potting, and long-lining activities have extended into deeper waters and now occur to <1500 m depth. In Ireland, major damage to deep-water corals has been linked to this recent expansion of deep-water fisheries, particularly for orange roughy (Wattage *et al.,* 2011). Cold-water corals are long-lived, slow growing, and fragile, making them especially vulnerable to physical damage, and as such they may take centuries to recover from damage, if at all (Hall- Spencer & Stehfest 2008; Glenn *et al.,* 2010).

Modiolus and *Sabellaria* reef areas have both suffered widespread and long lasting damage due to bottom fishing activities (Holt *et al.,* 1998). *M. edulis* reefs, oyster reefs and *L. hians* beds, as well as their associated communities, have also been found to decline in areas subjected to bottom-towed fishing gear (Cook *et al*., 2013). The gear damages the reefs leaving a 'flattened' appearance, causing a reduction in habitat complexity, and a removal of hard substratum for the attachment of epifauna. Repeated damage also leads to declines in associated species such as *A. digitatum* (Magorrian & Service, 1998).

Reports of loss of *S. spinulosa* reef are widespread because of the link between *Sabellaria* reefs and the Pink Shrimp *Pandalus montagui*, fishery. Fishermen have claimed to deliberately destroy reef that is in the way of shrimp trawling, to prevent damage to their gear (Holt *et al*., 1998; OSPAR, 2009d). *S. spinulosa* tubes are relatively fragile and recovery of reefs is impossible while the fishery activities persist in the area (Holt *et al.,* 1998). Physical impact from gear can break and damage reef structure, and the fragmentation of the habitat makes it more vulnerable to further damage (Sanders *et al.*, 2016). However, if only a small amount of damage occurs and provided the organisms are not removed from their tubes, their natural capacity to repair the reefs has been shown to allow recovery within a few days (Vorberg, 2000; OSPAR, 2009d). Potting and net fishing are also thought to cause damage to *S. spinulosa* reefs. As a result of these impacts, Fariñas-Franco *et al.* (2014) declared that fishing activities are thought to be the single biggest threat to *S. spinulosa* reefs.

Scallop dredges and bottom trawls have been widely documented in damaging *Modiolus modiolus* reefs around Ireland and the UK by reducing habitat complexity, removing epifauna and in some cases disturbing sediment which can lead to smothering of remaining taxa. Queen Scallop fisheries in particular have been associated with *Modiolus* reef and repeated disturbance has been shown to eliminate beds entirely, for example in Strangford Lough, Northern Ireland (JNCC, 2007; Sanderson *et al.,* 2008; OPSAR 2009c). Because of the longevity and unpredictable recruitment of the species, *M. modiolus* are particularly sensitive to physical disturbance, with recovery times estimated to be at least 12-20 years and longer in more highly impacted areas (Dinesen & Morton 2014; Fariñas-Franco *et al.,* 2016). However, static gears, such as long-lines, gill netting and potting, have been shown to have comparatively little impact on the structure of *M. modiolus* beds (OSPAR 2009c).

Recent studies indicate that scallop dredging is a likely cause of a decline in *L. hians* populations (Hall-Spencer & Moore*,* 2000a, b). The fragility of the shell makes *L. hians* vulnerable to damage from any form of physical impact, in particular moorings, hydraulic dredging and scallop dredging (Hall-Spencer & Moore, 2000b). This physical impact also causes widespread damage to the surrounding reef and faunal community, by destroying the nest of byssal threads. Hall-Spencer (1999) found that *L. hians* communities had still not recovered four years after scallop dredging had occurred in some habitats. As such, it may be assumed that the recovery of *L. hians* reef may be relatively slow, which could be the result of a combination of life history traits and local conditions.

Previously, *Ostrea edulis* beds were targeted directly by dredgers, as part of the commercial oyster fishery. However, with the collapse of the fishery, the main threat to *O. edulis* beds is now indirectly caused by bottom trawls and dredges targeting bottom fish and bivalve molluscs. Trawling damages both *O. edulis* and associated epibenthic species, reducing epifaunal abundance and leading to degradation of the habitat (OSPAR, 2009c). The slow-growing and reproducing, long-lived nature of *O. edulis* also means it take much longer to recover (20–50 years) than taxa with shorter life spans, however recovery can vary widely between ecosystem (Strain *et al*., 2012)

As with the above species, scallop dredging is the main activity resulting in damage to *Mytilus* beds, which removes the mussels as well as the surrounding substratum, and therefore the associated communities. Re-suspension of sediment, which also occurs during the process, has the potential to further smother the habitat, resulting in secondary impacts. The damage to the reef structure increases the vulnerability of the remaining reef to storm damage or other anthropogenic impacts (Mainwaring *et al.,* 2014).

The fragile nature of *Serpula vermicularis* reef also makes it vulnerable to mechanical damage. Otter trawling for *Nephrops* and scallop dredging have been reported as threats to the reef habitat. Static gear used in these areas includes the use of traps and pots for *Nephrops* and Velvet Crabs *Necora puber*, and weighted drums for Common Whelks *Buccinum undatum* (Moore *et al.,* 2006).

Table 6 The impact of different gear types on different reef habitats based on current literature (Source: Foley *et al*., 2010). The impacts on the biological and physical structure are scored with 1 = lowest impact and 3 = highest impact. The impact on the physical structure consists of damage to reef, while impact on biological structure includes impacts on the diversity of associated fauna.

Gear type	**Impact**	**Cold-water corals**	***Sabellaria* reef**	**Bivalve beds**
Long lines (bottom set)	Physical	2	1	2
	Biological	1	1	1
Gill nets (bottom set)	Physical	2	1	2
	Biological	1	1	1
Bottom trawl	Physical	3	3	3
	Biological	3	3	3
Pots	Physical	1	1	1
	Biological	1	1	1
Dredge methods	Physical	3	3	3
	Biological	3	3	3

4.1.2 Aquaculture and Moorings

Another area of concern relating to physical impact on biogenic reef is that caused from boat moorings and damage associated with aquaculture cages. Small boat moorings can cause damage through scouring of the reef by the mooring chain. Anchoring from small vessels can also pose a significant risk as this is generally uncontrolled and so can cause damage in various areas, affecting previously undamaged reef habitat. Areas of reef can be decimated during an anchoring event, especially for more fragile structures such as *Serpula* or *Sabellaria* reefs (Moore *et al.,* 2006). The shell of *L. hians* is thin and delicate so that mechanical impact with, for example, mooring chains, can lead to high levels of mortality (Hall-Spencer & Moore*,* 2000b).

Anchors dragging through *O. edulis* beds have also been shown to cause significant local damage to the reef by breaking off clumps of oysters and destabilising reef structures. This also makes the reefs more susceptible to further damage by predation or wave action (OSPAR, 2009c).

The presence of salmon cages to nearby *Serpula* reef appears to have had no obvious adverse impact on the distribution or abundance of reefs with regards to effluent. However, mooring of the cages has been shown to cause damage. During a survey of Loch Creran, Scotland, Moore *et al.* (1998) found patches of destroyed reef in the vicinity of moorings caused by mooring chains scraping along the seabed. To minimise damage it was suggested that moorings near *Serpula* reef should be minimised and that the length of mooring chains should be carefully assessed (Moore *et al.,* 1998).

Oyster and mussel farming also have the potential to cause damage to both rocky and biogenic reef. Oyster farming is generally carried out in shore-based sedimentary habitats and so poses less of a threat than mussel farming, however it can cause damage in areas where the activity intersects with reef. Previously, mussel farming has been recorded in areas of dense *Modiolus*; the risk posed by mussel farming lies predominantly in damage from ancillary activities, such as the mooring of vessels and work platforms. The deposition of dead mussel shells from the floating structures can also cause damage to other reef structure such as those formed by serpulids *e.g. Sabellaria alveolata* (Holt *et al.,* 1998; Moore *et al.,* 2006). The smothering of reefs by faeces and pseudofaeces may also pose a problem, however it is currently unclear if this results in any harm to the species (Holt *et al.,* 1998).

Further impacts from aquaculture relating to eutrophication and nutrient enrichment from uneaten food and faeces are covered is Section 4.4.1

4.1.3 Infrastructure Development

Infrastructure developments such as oil and gas exploration, aggregate extraction, mining and coastal developments have the potential to have a severe impact on reef habitats. The location of these activities in Irish near-shore waters are shown in Figure 7.

Hydrocarbon extraction and development of offshore installations could have a severe effect on deep-water coral habitats, primarily through the impact of placement of structures, *e.g*. oil platforms, anchors, pipelines, which have the primary impact of physical destruction of the habitats. This is similar to the effects of cable laying for electricity and telecommunications (Freiwald *et al.,* 2004). Cables and pipelines are laid across seas and oceans. Although there are no known examples of cables cutting through coral areas, there has been little examination of this possibility, that if laid near coral habitats, the disturbance associated with it may cause physical damage (Freiwald *et al.,* 2004). For example, ships normally use heavy anchors which are moved forward during the placement or repair of pipelines and cables, physically damaging corals in a much larger area than the area damaged by the pipeline or cable itself.

The effects of discharges associated with the oil industry such as drilling mud and drill cuttings can also have secondary impacts on corals, through increased sedimentation, which in turn could lead to smothering. Burying cables will also resuspend sediment, potentially smothering nearby habitats (Hall-Spencer & Stehfest, 2009; Foley *et al.,* 2010). For further impacts on the effects of sedimentation on reef habitats see Section 4.3.2.

The potential for cold-water corals to recover after physical damage is uncertain but is likely to take considerable time (>5 years), however this is dependent on the severity of damage and the size of the surviving coral fragments (Hall-Spencer & Stehfest 2008; 2009). Other threats to cold-water coral habitats include mining of deep-sea minerals, disturbance associated with hydrocarbon exploitation and carbon capture and storage, all of which are likely to have potential impacts similar to those described above (Hall-Spencer & Stehfest, 2008).

Coastal construction has altered the shape of the coastline and impacted on the substrates present along shores through the development of ports, harbour and shore defences, all of which have the potential to significantly impact reef habitat. This disturbance can be through a number of means, including physical destruction, removal of habitat or through potential hydrological changes such as changes in sediment or water flow (See Section 4.3 for more details on hydrological impacts).

The impacts of coastal developments on sensitive reef habitats are not fully known and may have very different effects depending on the area and the species present. Coastal constructions in sedimentary dominated habitat may provide suitable habitats for rocky reef organisms to settle, but in rocky areas could represent a threat due to the reduction in structural complexity of rocky shores, or the removal or hard substratum for species settlement (JNCC, 2007). This is of particular concern for certain rocky shores such as sheltered limestone reefs or upper estuarine bedrock which are scarce habitats and therefore vulnerable to localised impacts (Hill *et al.,* 1998).

Smooth sea walls have limited topographical complexity and provide little in the way of microhabitats. As a result, an impoverished community and reduced diversity are often seen on artificial structures. More complex blocks/boulders which are sometimes used for the construction of coastal defences may provide abundant microhabitat space which could lead to communities similar to those on the surrounding natural substrata (Hill *et al.,* 1998). However, the removal of substratum and the physical loss of habitat have been shown to be particularly damaging for mussel and oyster beds and recoverability is considered low for these species (Mainwaring *et al.,* 2014). Oyster spat usually settle on the shells of adult oysters, so substantial removal of an existing bed reduces suitable settlement areas for subsequent generations, further hindering recoverability (Holt *et al.,* 1998). In addition to removal of suitable substratum or reduction in habitat complexity, coastal development can also result in coastal squeeze. This results in the loss of coastal habitat due to the restriction of intertidal communities against a fixed boundary *i.e*. a seawall and squeeze due to sea level rise thereby reducing the intertidal area and diminishing the quality and quantity of intertidal habitats. This can have a particularly negative impact on geogenic reef, due to a decline in settlement substrate for reef-forming species, resulting in a decline in large macroalgal habitats and therefore loss of habitat complexity (Airoldi & Beck, 2007).

Sabellaria alveolata is also susceptible to coastal development through the potential shift in sediment regime, as both large scale increase and decreases in sand can be potentially damaging (Holt *et al.,* 1998). Altered hydrodynamics (*e.g*. due to coastal engineering works) and the installation of infrastructure such as pipelines and offshore wind turbines may also have a detrimental effect (Sanders *et al.*, 2016).

Aggregate extraction has also been shown to cause severe direct damage to *Sabellaria* reefs, in particular *S. spinulosa* which, due to its habitat requirements, is often located in areas where aggregate extraction is likely to occur. Aggregate extraction causes considerable damage to *Sabellaria* reef structures by physically breaking up the reef structure leading to loss of reef function, and in severely impacted areas can lead to complete loss of reef habitat (Pearce *et al.*, 2011). The extent of *Sabellaria* reef structures and the speed of recovery from this damage are still not fully understood (Holt *et al.,* 1998). However, Pearce *et al.* (2007) suggest potential recovery of *Sabellaria* reef at dredge sites within 6 months of the cessation of extraction activities.

The physical impacts of marine aggregate extraction arise from removing the substrata and altering the seabed topography, physical removal of species and disturbing the benthic community, reducing the diversity of benthic species (JNCC, 2007). This has the potential to have a considerable direct impact on biogenic reef within the immediate area. Due to the strong co-occurrence of *Sabellaria* reef with areas of aggregate extraction, these species are particularly susceptible. However, mussel beds are less likely to co-occur in close proximity to aggregate extraction areas and are therefore considered less likely to be impacted by aggregate extraction, although are equally as vulnerable to the impacts in areas where they co-occur (Hendrick *et al.,* 2011). The secondary impacts of aggregate extraction can also be large, and mostly comprise of increased sedimentation and potential smothering of benthic species. The effects of sedimentation on reef habitats are discussed in Section 4.3.2

However, the effects of aggregate extraction are likely to be relatively localised and therefore measures can be implemented to mitigate the degree of impact, unlike some coastal engineering which can act over large scales due to the alteration in hydrological regime (OSPAR, 2009d).

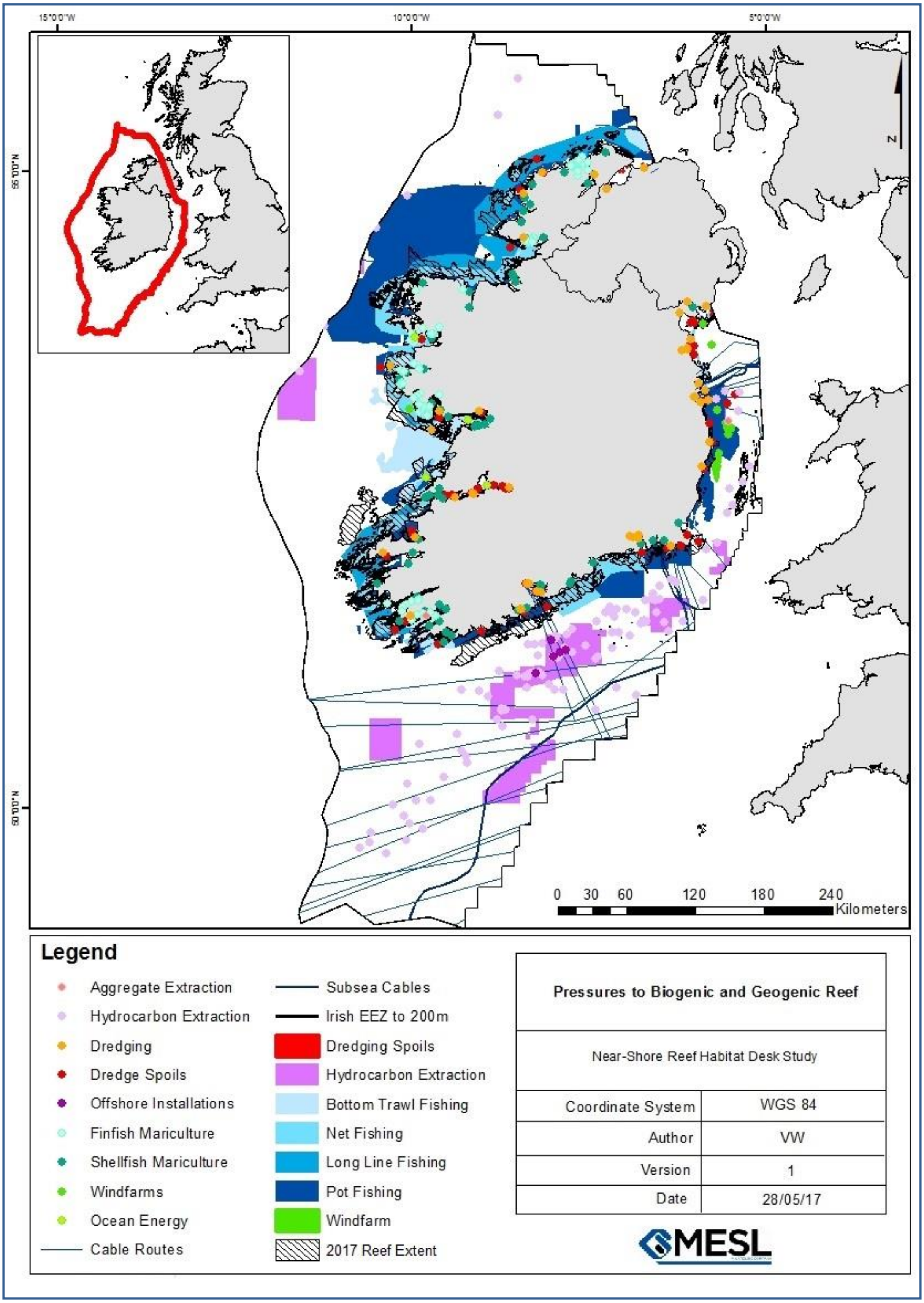

Figure 7 Locations of potential threats to biogenic and geogenic reef located in near-shore Irish waters from physical impacts and disturbance (Source: EMODnet, 2016).

4.2 Biological Pressures

4.2.1 Introduction of Non-native Species

The accidental introduction of non-native species is probably the most difficult anthropogenic impact to control (Hill *et al*., 1998). Non-native species can be introduced though several vectors including ballast water, hull fouling, aquaculture and stepping stone effects (*e.g*. offshore wind farms). The increase in non-native marine species introductions is causing concern in Europe (Birkett *et al.,* 1998) and the direct or indirect introduction of non-indigenous species, their subsequent spreading and potential ability to out-compete native species can have significant effects on reef species (Hill *et al*., 1998; Mainwaring *et al.,* 2014).

One introduction of potential significance to geogenic reef is the Japanese Kelp *Undaria pinnatifida*. This species has recently spread from northern Brittany to the Republic of Ireland (Carlingford Lough, Sept, 2014), Northern Ireland (Carrickfergus Marina, Sept, 2012) and the south coast of England (Birkett *et al.,* 1998). Initially introduced for aquaculture, this species has since spread and it is thought to compete with native kelp species, in particular *Saccorhiza polychides*. However, the full impacts on rocky shore communities are not fully known (Birkett *et al.,* 1998; Hill *et al.,* 1998).

Reef-forming shellfish populations are also sensitive to the effects of invasive and non-native species. *Ostrea edulis* populations are known to be negatively influenced by the introduction of the slipper limpet, *Crepidula fornicata* and in some areas oyster beds have been severely degraded by the introduction of this species. *C. fornicata* is a filter feeding gastropod native to the east coast of the Americas which, due to its filtration activities, creates an accumulation of pseudofaeces and fine sediment during feeding. This accumulation of sediment degrades the seabed, which prevents recruitment to oyster beds, resulting in a fall in population numbers (OSPAR, 2009d). *Mytilus edulis* is also affected by the introduction of *C. fornicata,* which is able to out-compete mussels for food and space, replacing mussel populations. *C. fornicata* also alters the structural complexity of mussel beds, having adverse effects on other associated species (Mainwaring *et al.,* 2014). Thieltges (2005) reported a 28-30% mortality of *M. edulis* when *C. fornicata* was introduced to beds in experimental studies. Pearce *et al.* (2007) also found *Crepidula fornicata* in high numbers associated with *Sabellaria spinulosa* reef, however it was not clear from observations whether *C. fornicata* were attached to reefs directly or if they were occurring in the gaps between aggregations. Insufficient evidence therefore exists to definitively state if *C. fornicata* has a negative impact on *Sabellaria* reefs.

The Pacific Oyster *Magallana gigas*, is said to have similar effects on *M. edulis* populations as those of *C. fornicata*. The high fecundity, long-lived pelagic stage and high dispersal potential of *M. gigas* make it a particular threat, as it is able to easily overgrow mussel bed in both rocky and sedimentary habitats (Fariñas-Franco *et al.,* 2014). *M. gigas* is also the most widely grown bivalve in aquaculture around the world at present, aiding in the spread of the species (Mainwaring *et al.,* 2014). In France, *Sabellaria alveolata* reefs are also becoming increasingly colonised by the Pacific Oyster, where it is thought that the high filtration rates of this species may enable it to outcompete *Sabellaria* for food (Dubois *et al.,* 2006). Such studies suggest the Pacific oyster has the potential to compete with biogenic reef species in Irish and UK waters (Hendrick *et al.,* 2011).

The invasive species *Didemnum vexillum,* the Carpet Sea Squirt, and *Botrylloides violaceus* are both suspension feeding tunicates capable of forming large colonies, which are highly competitive and quick to colonise new substrates. Both are reported to grow on and over *M. edulis* beds, as well as many other species such as barnacles, bryozoans and other tunicates, and in doing so they smother the animals underneath. *D. vexillum* has been seen to restrict the opening of the mussel valves, preventing feeding and leading to increased mortality (Mainwaring *et al.,* 2014).

Corella eumyota is a solitary tunicate, found currently along the Irish coastline. It is known to colonise a wide range of substrata including native oysters, intertidal cobbles and boulders, and other species associated with these habitats including conspecifics. *C. eumyota* is able to survive all year round allowing it to colonise substrata during times when seasonal organisms are not present during winter months. It is also able to colonise mussel seed beds (Mainwaring *et al.,* 2014). The presence of *C. eumyota* can therefore inhibit the settlement of reef species and prevent reef formation by outcompeting reef species for space.

However, it should be noted that the impact of an introduced species on reef communities varies from case to case and so the full effects of non-native species introductions are not clearly understood. For example, *Elminius modestus* can displace native barnacles on sheltered shores, however they have little effect on rocky shore structures, and in exposed locations native species can often outcompete *E. modestus*. *Sargassum muticum* grows rapidly and can clog coastal waterways and can affect native species on rocky shores and in rockpools due to shading, however it does not seem to directly compete with native species (Hill *et al*., 1998). Therefore, further research on the effects of non-native species to reef habitats within Irish near-shore waters may be required to obtain a clearer understanding of the detrimental impacts of non-native species. In addition, little information is known about the impacts of non-native species on cold-water coral reefs, and therefore further research in this area may also be needed.

Overall, the main impacts of invasive non-native species are from out-competing native species for food and space, inhibiting reef formation or degrading reef structure. Some non-native species may also overgrow and smother reef habitat leading to reef mortality. Both impacts lead to the loss of reef structures and reduction in reef function, having a negative impact on species abundance and diversity within the habitat.

4.2.2 Removal of Target Species - Overfishing

The biogenic reef-forming species *Mytilus edulis*, *Modiolus modiolus* and *Ostrea edulis* are themselves important fisheries, which makes them vulnerable to overexploitation (Holt *et al.,* 1998). The sensitivity to removal can be characterised as the immediate direct impact of harvesting and subsequent indirect effects from the methods used to extract them, which can lead to further declines in populations.

Mytilus edulis is an important fishery across the UK and Ireland, and collection of mussels through several techniques has been shown to affect both mussel populations and the structure of sediment and associated species in the area (Fariñas-Franco *et al.,* 2014).

Dredging is a key method for harvesting mussels. Dredging can have several negative impacts on reef habitats through the removal of sediment along with the mussels and their associated fauna, which damages the reef structure, prevents recovery and decreases species richness. The temporary re-suspension of sediment also occurs during dredging which can result in localised smothering (Holt *et al.,* 1998). Mussels are also regularly hand collected by fisherman for bait and food from intertidal beds, which can also result in significant damage to reef habitat. Associated trampling of the remaining habitat can also have a significant impact, as damage can lead to patchiness within the habitat, destabilising the structure and making it more susceptible to wave action (Mainwaring *et al.,* 2014).

There is limited knowledge on the sensitivity of *Modiolus modiolus* reef to human impacts, however *M. modiolus* is known to be targeted as fishing bait. It is generally collected on a local scale; however, some areas have seen large declines in populations, which have not since recovered (Cook *et al.,* 2013). In some areas, most notably Scotland, *M. modiolus* is also part of a small scale fishery and is widely eaten in the locality (Holt *et al.,* 1998).

Ostrea edulis was historically a productive fishery in Ireland, however landings in Europe have been in decline since the early 18th century and populations have been seen to collapse from over exploitation. An example of this is in Strangford Lough in Northern Ireland in the 1890's. Despite some recovery to populations since this time, subsequent declines have been attributed to unregulated harvesting in the area (Smyth *et al.,* 2009) along with slow growth rates and poor recruitment success (OSPAR, 2009c).

Damage to *Sabellaria alveolata* reef has also been observed during collection for use as fishing bait. Trampling of reefs during collection and the act of breaking open tubes and removing the worms can have an effect on the integrity of the reef structure, although nowhere has this been seen on any intensive scale (Holt *et al.,* 1998). Damage to *S. alveolata* reef has also been recorded as a secondary effect from the collection of mussels and oysters, when the species are seen in association with each other (Dubois *et al.,* 2002).

Several rocky shore species are also commercially exploited. The main targeted species are macroalgae (Knotted Wrack *Ascophyllum nodosum* and kelps, *Laminaria* spp), molluscs (*e.g*. *Littorina littorea*) and crustaceans (*e.g*. *Cancer pagurus*). The removal of any species can have detrimental effects on other members of the community by altering the structure and functions of the habitat and reducing habitat complexity and diversity. Macroalgae are a key component of intertidal geogenic reef habitat, are responsible for much of the primary production on rocky shores, and are important providers of microhabitat for other species, whilst mobile gastropods are important grazers and crustaceans *e.g*. *Cancer pagurus* are important predators of rocky shore, geogenic reef communities (Hill *et al.,* 1998).

Mechanical harvesting of kelp has been shown to have a more significant direct influence on kelp biotopes as it removes the whole plant (Birkett *et al.,* 1998; Hill *et al.,* 1998). In Europe the most commonly harvested species are *Laminaria digitata* and *L. hyperborea*. Although research has been conducted on the effects of harvesting on the kelp species themselves, less is known of the effects of kelp removal on species associated with kelp biotopes. However, loss of reef structure, loss of habitat and increased sensitivity of reef to wave energy are all likely to have negative impacts on associated species, leading to decreases in abundance and diversity in geogenic reef habitats. Some studies have suggested that recovery of associated macroalgal species may be regained within 3 years of canopy removal, however some studies have indicated that full recovery may not occur for over 10 years after harvesting of mature kelp plants (Birkett *et al.,* 1998).

Hand harvesting of *Ascophyllum nodosum* has a lesser impact on the surrounding environment compared to mechanical harvesting methods. *A. nodosum* can re-grow after careful hand cutting however it is slow to recruit after it has been completely removed. An additional problem associated with harvesting and collection of species from geogenic reef habitats is disturbance; trampling during harvesting can damage species on the shore and rocks turned over during the collection of peeler crabs or winkles might not be replaced, damaging macroalgal and sessile faunal species attached to the boulders (Hill *et al*., 1998; JNCC, 2007)

4.3 Alteration to Hydrological Flows and Sedimentation Rates

4.3.1 Water Flow Change

Changes in water flows, currents and wave energy levels have the potential to impact both biogenic and geogenic reef habitat. Anthropogenic pressures have the potential to influence water movements through the development of coastal infrastructure, dredging activities, and offshore activities.

Changes in water flow can have a detrimental effect on reef habitat structure and functions in several ways. Larval dispersion and recruitment of reef-forming species is often reliant on water currents to carry propagules, and reef habitats may be dependent on the supply of nutrients or reef building materials born by water currents. Disruption to these supplies is likely to be detrimental to reef habitat structure and functions (Hendrick *et al.,* 2011). This is particularly true of *Sabellaria* reefs which require a flow of suspended sediment with which to construct their tubes. A decrease in the flow of sediment can cause complete or near complete die-off of reefs in extreme cases (Fariñas-Franco *et al.,* 2014). *Ostrea* beds can also be severely affected by alterations to hydrodynamic flows as they tend to occur in areas of moderate to strong tidal currents. Any factors which alter the tidal flow rates could therefore affect the viability of *O. edulis* beds by restricting nutrient filtration. It could also alter the associated communities and potentially lead to loss of the beds (OSPAR, 2009c).

Changes or increases in wave energy in the intertidal zone could have a large impact on geogenic and biogenic reef habitats. The effects of increased wave action due to increased storm disturbance are discussed in Section 4.5.3. In the intertidal zone, increased tidal flow could prevent larval settlement, which could destabilise reef structures by preventing recruitment and thereby preventing recovery of reef structures from any anthropogenic impacts.

Increased tidal flows may also cause damage to intertidal geogenic reef. Although the geogenic reef structure such as bedrock or boulders are unlikely to be affected by changes in water flow, macroalgae are a key component of geogenic reef and strong tidal flows may dislodge species from the shore reducing habitat complexity. Decreases in large macroalgal species are often paralleled by an increasing abundance of turf-forming, filamentous or other ephemeral algae that once established often prevent recolonisation of canopy-forming algae, preventing reef recovery (Airoldi & Beck, 2007).

The development of other coastal and offshore structures is also likely the affect water flow in an area. The offshore wind farm industry is in its infancy and the degree to which these structures alter the flow of water and sediments, and their resulting impacts of reef habitats remains largely unknown (Fariñas-Franco *et al.,* 2014). However, evidence suggests that the physical presence of the turbine structure can reduce water flow leading to localised changes in water movement, energy and turbulence. These changes can in turn cause benthic sediment scouring and resultant habitat changes (Boehlert & Gill, 2010). Scour most commonly occurs at the base of wind turbines and the presence of any biogenic reef structures in this area may therefore be affected.

In the water column, modifications to water movement could lead to changes in turbulence and stratification, potentially altering vertical movements of marine organisms, altering food availability for some species (Boehlert & Gill, 2010). For mussel beds, which require moderate water flows to facilitate filter feeding, a reduction in water flow may therefore result in lower food supply and loss of filtering ability, reducing reef function. A reduction in current flow could also have a severe impact on *Sabellaria* reef habitat if less sediment is transported for the construction of reef habitat.

4.3.2 Sedimentation

Sedimentation on reef habitats has the potential to cause major impacts on biogenic and geogenic reef structure and functions. Increased sedimentation may arise from 'natural' land run-off and riverine discharges or from anthropogenic activities such as dredging, disposal at sea, cable and pipeline burial and secondary effects of construction works, *e.g*. breakwaters. This pressure can also relate to changes in turbidity from suspended solids of organic origin, however these are discussed with eutrophication in Section 4.4.1.

Smothering as a result of excessive sedimentation can result in physiological stress in benthic organisms. Some species such as *Mytilus edulis* are able to tolerate short term and repeated burial, however smothering does cause changes in respiration and feeding efficiency; a reduction in feeding rate also means that energy is diverted to somatic growth and not to reproductive growth. Longer term burial can cause physiological stress and can prevent recruitment into the population hindering reef recovery, and prolonged smothering can lead to reef mortality (Fariñas-Franco *et al.,* 2014). Although the effects of sedimentation on *M. modiolus* are not entirely known, it is thought that *M. modiolus* are more sensitive to sediment burial than *M. edulis* and therefore high rates of sedimentation are likely to lead to complete or near-complete die-off of *M. modiolus* reef (Fariñas-Franco *et al.,* 2014).

An increased suspension of fine sediments can also influence suspension feeding fauna by clogging their filter-feeding mechanisms (Bilotta & Brazier, 2008; Rhoads & Young, 1970). *Ostrea edulis* are able to respond to short term increases in suspended sediment by increasing the production of pseudofaeces in order to expel accumulated silt. However, this response has a high energetic cost due to the physical effort of filtering increased particles and over increased periods can lead to decrease in animal health and eventual mortality (Smyth *et al.,* 2009). Increased sedimentation can also impact on the settlement of larvae and subsequent recruitment into the population as settling oysters require clean, unsilted areas to settle on (Tully & Clarke, 2012). Therefore, increased sedimentation has a negative impact on *Ostrea edulis* reef by reducing reef function and causing eventual loss of reef habitat.

Sabellaria spinulosa and *Sabellaria alveolata* reefs however are thought to be unaffected by small increases in sediment in the water column. This is due to their preference for more turbid waters and their ability to incorporate sediment into reef structures. Therefore, increased sedimentation may have a positive impact on reef development (Pearce *et al.,* 2007; Hendrick *et al.,* 2011; Fariñas-Franco *et al*., 2014). However, excessive increases in sedimentation can clog feeding appendages, and prolonged periods of smothering from sediment released during marine construction or through spoils dumping can pose a significant threat to *Sabellaria* reef, leading to mortality in the reef (Rhodes & Young, 1970; Fariñas-Franco *et al.,* 2014).

The effect of sedimentation on corals that form deep-water reefs is not fully understood however there is generally a negative trend between coral growth rate and sedimentation. One of the main sources of this sedimentation can be from discharges of rock cutting, drilling fluids and other discharges from mineral and oil extraction. The deliberate dumping or disposal of material (such as dredged sediments) on coral reef ecosystems is likely to physically harm corals and reefs by covering them or damaging their structure. Although there are few published studies on the exact effects of drilling mud of the survival of *L. pertusa* and other cold-water coral species, the effects of these extracts on cold-water corals should be given serious consideration (Freiwald *et al.,* 2004).

Increased sedimentation has been shown to have a number of detrimental impacts on geogenic reef habitats, such as inhibiting settlement of larvae, reducing recruitment to the population, smothering young algae resulting in mortality and in areas of high water movement the additional sediment can scour the rocks removing newly settled algae (Birkett *et al.,* 1998). Sedimentation and increased turbidity from coastal developments have been shown to wipe out local kelp beds by reducing the light available for photosynthesis (Birkett *et al.,* 1998), leading to change in the structure of geogenic reef by reducing habitat complexity. Light penetration determines the lower limit at which algal species can grow and increased turbidity will likely alter reef distribution and as primary producers which utilise daylight for energy through photosynthesis, recovery of geogenic reef from any decreases in water clarity may be prolonged.

4.4 Pollution or Chemical Changes

4.4.1 Nutrient Enrichment/Eutrophication

Biogenic and geogenic reefs are threatened by eutrophication typically caused by the excess loading of nutrients in the ecosystem, largely due to terrestrial run-off or sewerage dumping. The effects of eutrophication include decreasing light penetration, increased organic sedimentation, and in severe cases deoxygenation, algal blooms and changes in community structure.

Rapid urbanisation and coastal agriculture, leading to organic enrichment, have been attributed as the main cause of nutrient enrichment and eutrophication in marine systems (Mainwaring *et al.,* 2014). This is particularly true for a seasonal ‘‘green tide’’ of *Ulva* spp. which have been observed on *Sabellaria alveolata* reefs. The effects of this on the structure of *Sabellaria* reefs are mainly unknown, however algal overgrowth has been seen to lower the rate of recruitment and increase the mortality of new recruits on *S. alveolata* reefs and to have a generally negative effect on habitat function (Dubois *et al.,* 2006).

Algal blooms and high levels of hazardous substances have also been shown to have a negative effect on many of the bivalve reef-forming species, due to the characteristic filtering of water (HELCOM, 2013). *Mytilus edulis* are among those species that have been shown to be negatively affected by algal blooms. For example, blooms of the algae *Phaeocystis* spp. have been observed to block the mussel's gills, reducing clearing rates, and at high levels have caused a complete cessation of clearance (Holt *et al.,* 1998). Blockage of the gills is also likely to reduce ingestion rates, prevent growth and cause reproductive failure (Holt *et al.,* 1998). Phytoplankton blooms can also lead to oxygen depletion, resulting in mass mortality of mussel populations leading to a loss of structure and functions of bivalve reefs (Fariñas-Franco *et al*., 2014).

Increased pollution has also been shown to affect the physiological condition and reproduction rates of both *Modiolus modiolus* and *Mytilus edulis* reefs (Fariñas-Franco *et al.,* 2014). However, a number of studies have also highlighted the ability of *M. edulis* to utilise the increased volume of organic material. Reid *et al.* (2010) noted that *M. edulis* could absorb organic waste products from salmon farms with great efficiency, leading to increased shell length, wet meat weight, and condition index at locations within 200 m from a farm in the Bay of Fundy. *M. edulis* reef is also often recorded near sewage outflows, suggesting that they display a high tolerance to the increase in organic material (Mainwaring *et al.,* 2014).

The discharge of organic factory effluent has also been noted to adversely influence the growth of *Serpula vermicularis* reef. Moore *et al.* (1998) showed that no *S. vermicularis* were recorded from a 1 km stretch of coast centred on the discharge from an alginate factory. The organic effluent released appeared to completely eliminate reef within 1 km of the study area and reduced reef development for even greater distances, by reducing areas suitable for colonisation by *Serpula* reef habitat. A negative relationship between high nutrient concentrations of phosphate, nitrate and silicate and the distribution of *L. pertusa* reef has also been recorded (Davies *et al*., 2008). Reduced *Serpula* reef development will negatively affect habitat function by reducing habitat complexity and the abundance and diversity of associated fauna.

Eutrophication from agricultural run-off or from waste nutrients from fish farms can cause local organic enrichment and increase turbidity in coastal waters. This can lead to phytoplankton blooms and can decrease light penetration in the water column, limiting photosynthesis and constraining kelp growth (Birkett *et al.,* 1998). Large volumes of waste material can also lead to anaerobic conditions and decreased oxygen in the water column due to the decomposition of organic matter (Birkett *et al*., 1998). Therefore, excessive enrichment in the intertidal zone may lead to mortality of macroalgal populations diminishing the structure of geogenic reef habitat.

S. spinulosa appears to be much more tolerant to high levels of eutrophication compared to other species, and only shows some sensitivity to very marked reductions in water quality (Fariñas-Franco *et al.,* 2014). *S. spinulosa* and the associated species assemblage (which typically includes attached filter feeders) are likely to be able to consume the extra organic matter, therefore enhancing reef growth and survival, as seen by the enhanced growth rates recorded on reef habitats in the vicinity of sewage disposal areas (Walker & Rees 1980). *Sabellaria* reefs are therefore unlikely to be affected by eutrophication.

4.4.2 Pollution and Contaminants

Pollution and contaminants in the marine environment are considered one of the largest and most widespread pressures to reef habitats. Contaminants from various hazardous substances threaten the quality of reefs (HELCOM, 2013) and fish farms, key producers of pollution in the marine environment threaten the structure of reef habitats.

Tributyltin (TBT), a persistent organotin, was widely used in Ireland as an antifoulant on shipping, small boats and yachts and on nets of salmon cages. It is known to be detrimental to a number of marine organisms and although its use is now banned, residual effects are still impacting marine species. TBT persists in sediment for some years and as such continues to affect susceptible species (Minchin, 1995).

TBT has a chronic impact on intertidal reef communities as it becomes concentrated in the surface layer of water and subsequently washes over rocky shore organisms. It has severe effects on settling larvae and has been shown to have particularly negative impacts on molluscs, for example on the Dogwhelk *Nucella lapillus,* an important intertidal predator (Hill *et al.,* 1998).

Settlement of *Limaria hians* in Mulroy Bay, Co. Donegal, showed a decline after the first documented usage of TBT. Minchin *et al.* (1987) showed that spat settlement fell to less than 2% of their former extent on beds near to salmon farms which used TBT as an antifoulant. Declines in *L. hians* abundance are noted to have further effects on the surrounding area, including destabilisation of the sediment and marked reductions in the abundance of sessile species (Hall-Spencer & Moore*,* 2000a). Despite these negative effects, a study by Minchin (1995) suggested full recovery of *L. hians* beds was possible nine years after the cessation of TBT use. This was attributed to the fact that *L. hians* is capable of reproducing at an early age, allowing for rapid recovery once settlement has commenced.

TBT has also been seen to negatively affect *Modiolus modiolus* populations and although little work has been done to assess their recovery, due to their longevity and sporadic recruitment, it is estimated that population recovery could take up to 25 years, if it occurs at all (Trigg, 2009). As a bio-accumulator, *M. modiolus* has the capacity to store high levels of contaminants, including hydrocarbon compounds and heavy metals in the shell and soft tissue. The impacts of these contaminants on reproduction and survival are not fully known, however, pollution from TBT, polychlorinated biphenyls (PCBs) and organic carbon have been seen to reduce species diversity within *Modiolus* communities (Fariñas-Franco *et al*., 2014).

Mytilus edulis and *Ostrea edulis*, like *Modiolus modiolus*, are bio-accumulators, due to their filter-feeding nature, and have also been seen to be affected by TBT. Prolonged exposure to TBT can lead to mortality due to bio-concentration of the pollutant, which can lead to reef degradation. TBT can also affect recruitment to reef populations by preventing reproduction, causing larval mortality or decreased growth rates of settled larvae thereby increasing the susceptibility of bivalve reef to other anthropogenic disturbance (Heral *et al.,* 1989).

Other contaminants which have been shown to cause mortality in *Mytilus* reef are diesel fuel and PCBs (Holt *et al.,* 1998). An experiment conducted by Smaal *et al.* (1991) assessed the bioaccumulation of environmental contaminants and their effects on the physiology of *Mytilus edulis* by recording the survival time of mussels exposed to air. Survival was significantly lower after 6 weeks of exposure to areas with high levels of PCBs and trace metals. Clearance rates were also reduced at the highest tissue concentrations. Although *Mytilus edulis* is considered relatively resilient to pollution, reductions in mussel density and in some cases displacement of communities has been recorded as a result of sewage pollutions (Fariñas-Franco *et al*., 2014). These same contaminants have a similar effect on the health and survivorship of *Ostrea edulis* (OSPAR, 2009c). The reduction in density has a negative effect on reef structure, reducing resilience to disturbance and reducing associated species diversity.

There is evidence to suggest that *L. hians* have a low tolerance to barium sulphate, a compound used predominantly in oil well drilling fluid (Chow *et al.,* 1978), compared with other species of bivalve such as *Modiolus modiolus*. It is thought that the compound affects the ability of *L. hians* to close their shell, further reducing the species' tolerance to other chemical pollutants within the water column (Trigg, 2009).

Despite the above findings, bivalves are generally considered relatively tolerant to contamination in the marine environment (Fariñas-Franco *et al*., 2014). *S. spinulosa* is also considered tolerant of chemical contamination and in some cases has been found to thrive in polluted areas (Sanders *et al.*, 2016). Despite this, some studies have shown that increases in coastal eutrophication can cause a shift in communities, allowing mussels to thrive and out-compete *Sabellaria* (OSPAR, 2009d).

Another contaminant in the marine environment often associated with aquaculture developments is Ivermectin. Ivermectin is a pesticide used to control sea lice on farmed salmon by targeting the neuromuscular system of invertebrates. The compound is toxic to some annelid worms and can reduce the abundance of other infaunal polychaetes (such as *Serpula vermicularis*), located in close proximity to aquaculture sites. Ivermectin is also lethal to starfish, shrimps and other crustaceans, so is likely to have high impacts on reef habitats (Hill *et al.,* 1998). The exact effects of the compound remain to be studied, however, since the pesticide is toxic to a wide range of invertebrates, presence of the chemical could impact rocky shore communities, by either reducing the competitive abilities of susceptible animals or by causing mortalities. It has also been shown to affect kelp biotopes by altering the ecological balance within the community (Birkett *et al*., 1998; Hill *et al*., 1998).

Intertidal geogenic and biogenic reef communities are sensitive to a range of environmental impacts, from chronic low impacts such as sewage pollution, through to acute factors including red tides and oil spills. The impacts of chronic disturbance are in most cases likely to be reversible, provided the issue is stopped. Recovery from acute impacts may be possible depending on the scale of the impact, but is likely to take much longer than from chronic impacts (JNCC, 2007).

Low intensity pollution and physical disturbance are the main sources of chronic impact to intertidal reef. Coastal areas are particularly susceptible to the effects of pollution, as discharges often occur close to the shore or into rivers where the shallow water limits the potential for pollutants to disperse. The most severe effects of sewage effluent discharge occur in semi-enclosed areas such as estuaries and sheltered bays (Hill *et al.,* 1998).

Oil spills on rocky shores can have a severe impact on intertidal reef communities. Contamination from hydrocarbons can destabilise communities leading to fluctuations and imbalances in species on the shore, often with an initial increase in *Fucus* spp. followed by high increases in *Patella* spp. Some studies have shown fluctuations between these two communities lasting at least 10 years before populations have recovered (Hill *et al.,* 1998). Decreases in macroalgae abundance can lead to reduced habitat complexity and therefore reduced species diversity, reducing the function of reef habitats in the intertidal zone.

There is currently little work on the variety of chemicals and contaminants (including dissolved and dispersed oil) which are known to enter the environment around offshore oil operations which may have lethal and sub-lethal effects on cold-water corals, however initial research shows they are likely to have a negative impact (Hall-Spencer & Stehfest, 2008).

4.5 Climate Change

Levels of CO_2 in the atmosphere are increasing, and associated impacts which may influence biogenic and geogenic reefs are predicted. The Intergovernmental Panel on Climate Change (IPCC) has provided several projections of atmospheric CO_2 and sea surface temperature (SST) changes into the next century. The most widely accepted prediction is a doubling of pre-industrial concentrations of CO_2, causing a subsequent increase in SST of 1 to 2°C by the year 2065 (Freiwald *et al.,* 2004). This rise in atmospheric CO_2 will also increase dissolved CO_2 levels in seawater, which in turn will result in a drop in ocean pH, known as ocean acidification. How these dramatic effects may influence reefs as a whole has yet to be studied, however, a decrease in the pH of seawater will not be beneficial to any calcium carbonate-driven ecosystem (Freiwald *et al.,* 2004) and a change in sea temperature may lead to a shift in the distribution or survival of species (Strain *et al.,* 2012).

4.5.1 Temperature Changes

On local and regional scales, rising temperatures can alter the range and recruitment dynamics of species, and reduce their fitness. Even in the relatively short term, temperatures are anticipated to rise by 1-3°C within the next century, which could have a significant effect on the distribution of species that occur in Ireland (Birkett *et al.,* 1998). There is already compelling evidence that climate change has had a substantial influence on the Irish Sea fauna over the last three decades (Strain *et al.,* 2012). However, understanding patterns of species response to climate change is not straightforward, due to factors such as current flow and barriers to species movement (JNCC, 2007).

Ireland and the UK straddle a major biogeographic boundary with many southern species reaching their limits in Ireland or southwest Britain (Hill *et al.,* 1998). The exact distribution range of species is usually variable, in response to changes in climate and as such species limits can fluctuate, responding to changes in climate. Increasing temperatures can therefore alter the distribution of species in the marine environment. Generally, warm-water species are likely to replace cold-water species, with cold-water species moving to more northerly latitudes or greater depths (Hill *et al.,* 1998; JNCC, 2007).

Modiolus modiolus is a northern temperate species and with climate change and increasing sea temperature, *Modiolus* reef formations may be pushed north. In a recent study it was predicted that at the current rate of temperature increase, 100% of suitable habitats for *Modiolus* reef within the UK would be lost by 2080, correlating to an increase in ocean temperature of 3°C (Morris, 2015). *O. edulis* on the other hand cannot tolerate low temperatures and therefore an increase in water temperatures is likely to have a positive effect on growth and survival, especially at its more northern distribution, where the spread of such reef habitats may increase (OSPAR, 2009c).

Populations of some intertidal reef species are very responsive to temperature changes, particularly those at the edges of their latitudinal ranges. Temperature changes could particularly affect kelp biotopes, resulting in depth distribution changes and reduced productivity of kelp species, with unknown consequences for reef habitats (JNCC, 2007). The distribution of barnacles *Semibalanus balanoides*, *Chthamalus stellatus* and *C. montagui* (key component fauna in intertidal geogenic reef habitat) is also determined by temperature by affecting each species' competitive ability. For example, at higher latitudes *S. balanoides* is more competitive, which restricts *Chthamalus* spp. to the high shore at more northerly distributions (Hill *et al.*, 1998).

Global sea temperatures are also rising in the deep-sea habitats, due to increasing amounts of anthropogenic CO_2 in the atmosphere. Rising sea temperatures will likely influence deep-sea coral calcification rates, physiology, and biochemistry. This in turn will negatively affect cold-water coral reef structure and functions, although specific ranges and thresholds are not yet known.

A study by Naumann *et al*. (2014) looked at cold-water coral calcification rates with increased ocean temperatures to assess whether calcification would be suppressed at upper thermal limits of both *L. pertusa* and *M. oculata*; *M. oculata* showed a higher tolerance to environmental change compared to *L. pertusa.*

M. oculata and L. pertusa are found generally in water temperatures between 4-12°C. Despite some declines in respiration rates with rising temperatures, results generally indicated that temperatures up to 12°C may not represent a limiting factor on the occurrence of cold-water corals, indicated by their positive physiological response (Naumann *et al.,* 2014). However, in Irish waters water temperature typically ranges from 5-17°C (Marine Institute Ireland, 2019). Therefore, increases in water temperature may reduce the number of suitable areas for cold-water coral reef formation.

Any positive effects of increased temperatures, for example increased primary productivity, may be offset by the negative impacts of increased disturbance from wave and storm surge action (see Section 3.5.3) that such changes may also bring (JNCC, 2007). The influence of water temperature on the prevalence of marine diseases that might affect reef habitats is also unclear, but higher temperatures combined with eutrophication and algal blooms can lead to lower oxygen levels, causing direct mortality of marine species (OSPAR, 2009c). Increasing temperatures can also alter the timing of ecological processes and there is potential for temporal mismatch in food recourse or settlement processes (JNCC, 2007).

4.5.2 Ocean Acidification

Ocean acidification is the decrease in pH of the ocean due to the increased uptake of atmospheric CO_2 into the water, and is enhanced by elevated atmospheric CO_2 associated with climate change. This uptake initiates a series of chemical reactions, increasing hydrogen ion concentration, lowering pH, and reducing the number of carbonate ions available in seawater (Longphuirt *et al*., 2010). These factors make it more difficult for marine calcifying organisms to form calcium carbonate, inhibiting shell formation and the accretion of carbonate skeletons. In recent decades, only half of anthropogenic CO_2 has remained in the atmosphere; the other half has been taken up by the terrestrial biosphere (20%) and the oceans (30%) (Guinotte *et al.,* 2006). Over the next century, these elevated concentrations of atmospheric CO_2 are expected to result in a reduction of the ocean surface water pH,from pH 8.1 to pH 7.7, as well as a reduction in carbonate ion (CO_3^{2-}) concentration (Parker *et al.,* 2013)

Ocean acidification is considered a substantial threat to all bivalve reefs and cold-water corals, since a drop in pH might impair calcification; this is also likely to affect any calcifying organism on geogenic reef or in association with biogenic reefs (Hansson *et al.,* 2009). All marine calcifying organisms tested to date have shown a similar negative response to decreasing carbonate saturation state (Guinotte *et al.,* 2006). Recent studies have shown a negative effect to echinoderm, bivalve, coral, and crustacean species, with impacts affecting fertilisation, larvae, settlement, and reproductive stages (Kurihara, 2008). Recent work suggests that molluscs are sensitive to changes in seawater carbonate chemistry. Molluscs are major producers of calcium carbonate ($CaCO_3$) in the marine environment. Studies on the responses of these species to ocean acidification suggest that larvae and adults will find it more difficult to deposit calcium carbonate shells and will suffer a range of negative impacts including changes in metabolism, acid-base status, reduced reproduction, depleted immune responses and increased mortality (Parker *et al.,* 2013). In response to elevated CO_2 levels, calcification rates in the Blue Mussel *Mytilus edulis* and the Pacific Oyster *Magallana gigas* decreased by 25% and 10%, respectively (Fabry *et al*., 2008). Berge *et al.* (2006) also found that under reduced pH conditions *M. edulis* growth was negatively affected, with reduced growth at pH 7.1 and virtually no growth at pH 6.7. However, results vary between studies and so the effects of reduced pH are not fully known (Parker *et al*., 2013).

The capture and sequestration of CO_2 from the atmosphere into deep waters has been proposed as a way of reducing global warming, with the assumption that ocean CO_2 disposal would reduce atmospheric CO_2. There are concerns about the consequences of this action on deep sea fauna, including the risk of impairing the ability of cold-water corals to lay down calcium carbonate framework structures, and as such ocean acidification has been suggested as a serious threat to deep-water reef habitats. The shift in carbonate chemistry associated with ocean acidification also reduces the saturation state of aragonite, a naturally occurring polymorph of calcium carbonate from which most framework-building corals build their skeletons. The aragonite saturation depth is predicted to become shallower with the advent of ocean-based carbon sequestration, making it more difficult for calcifying organisms at depth to maintain their calcified structures, potentially affecting reef growth (Freiwald *et al.,* 2004; McCulloch *et al.,* 2012; Armstrong *et al.,* 2014; Hennige *et al.,* 2014) The aragonite saturation depth varies geographically due to differences in temperature and water chemistry, but the North East Atlantic model predictions suggest that reefs are at risk (Jackson *et al.,* 2014).

Scientific research is currently assessing the resilience of cold-water corals to ocean acidification, and although the results are not yet conclusive (Armstrong *et al.,* 2014) lab experiments have shown that lowering carbonate ion concentration reduces calcification rates in tropical reef builders by 7–40%, and so, results in cold-water corals are expected to be relatively similar. Cold-water corals are therefore expected to build weaker carbonate skeletons with decreasing pH, possibly affecting reef structure and integrity. Hennige *et al.* (2014) showed that *Lophelia pertusa* respiration rate was significantly lower in fragments exposed to increased CO_2 than in control fragments after 2 weeks. Although growth rates of *L. pertusa* did not significantly change under different CO_2 conditions, the observed decrease in respiration rate highlights an energetic imbalance, where *L. pertusa* may be forced to use energetic reserves to maintain calcification rates (Hennige *et al.,* 2014).

There are also concerns that changing seawater chemistry could have an indirect, detrimental effect on deep-sea corals. Any potential associated change in the direction and/or velocity of currents could have a serious impact on their distribution, by limiting the amount of food and nutrients made available to them (Guinotte *et al*., 2006). A study by Naumann *et al.* (2014) also suggested that any change in settling substrate, velocity of bottom-currents, food supply, aragonite saturation state or seawater density could affect the growth and survival of cold-water corals. Changes in any of these factors, as an indirect effect of ocean acidification, will be detrimental to reef-forming corals.

4.5.3 Storm Disturbance

With climate change, extreme weather events, including changes to storm frequency and intensity, are predicted to increase over the 21st century. However, the consequences of increased storm activity to coastal ecosystems are largely unknown (Corte *et al.,* 2017). Significant changes in macrobenthic species richness, abundance and biomass have been associated with storms, resulting in significant changes to faunal diversity over time, mainly attributed to species loss (Corte *et al.,* 2017). Rocky shore communities are particularly susceptible to the effects of extremes in weather (Hill *et al.,* 1998).

Wet weather has the potential to reduce the salinity of rock pools, whilst extended periods of calm weather may reduce wave action, prolonging periods of exposure for species on the high shore or increasing emersion times for those on the mid and low shore, which has been reported to increase the mortality of barnacle cyprids (Hill *et al.,* 1998). Cold weather can cause freezing stress, and warm, dry weather may increase desiccation stress (Hill *et al.,* 1998).

Mytilus edulis beds are thought to be particularly susceptible to increased storm disturbance especially in the intertidal zone. This is due to decreased salinity, caused by increased storm runoff and from colder winters which have previously lead to mortality in mussel beds around the UK (Hendrick *et al.,* 2011). In contrast*, Modiolus modiolus* has been shown to be more susceptible to impacts from higher summer temperatures. However, more research is needed to understand the full effects increased storm disturbance might have on *M. modiolus* populations, as increased wave action is more likely to dislodge mussels and is likely to weaken reef structures (Hendrick *et al.,* 2011).

Other studies have also reported high mortality and slow growth in *O. edulis* as a result of high turbidity in winter months linked with low levels of organic matter, a problem which may become more prevalent with increasing storm events (Smyth *et al.,* 2009). Similarly, due to the instability of the structures *Sabellaria* spp. produce, increased storm frequency and intensity is considered the most likely factor to impact their survival in the event of climate change (Hendrick *et al.,* 2011).

Storm-induced wave damage can have a significant effect on kelp forests located within geogenic reef habitat, as frequently seen when entire kelp thalli are torn off and deposited on the strand-line. A less direct effect of storms is the increase in turbidity, which occurs due to sediment re-suspension. This affects rocky reef biotopes through reduced light penetration (Section 3.3.2) and increased silt deposition (Birkett *et al.,* 1998).

Higher wave energy during storms may also translocate and disperse large sediment volumes, which alter faunal assemblages present on the shore. This has been most widely documented for benthic invertebrates and algal communities and is likely to reduce the diversity on the shore due to species loss, due to burial, and reduction in habitat heterogeneity (Corte *et al.,* 2017). Increased wave action may also suspend fine-grained sediments which, when washed over the rocks can cause sand scour, removing small algae and newly settled larvae. Increased wave action can also dislodge organisms from the rocks.

Increased storm disturbance has a much greater impact in coastal areas and on intertidal reef communities, therefore species restricted to subtidal reefs are less likely to be affected. Storm disturbance is therefore unlikely to have a negative effect on cold-water coral ecosystems, however, little research has been done to quantify any effects of storm disturbance to subtidal communities.

4.6 Pressures and Threats Conclusion

The resilience or recoverability of some reef habitats, particularly offshore rocky and coral reefs, is generally considered low. Even small magnitudes of pressure, particularly from fishing activities, have the potential to affect ecological quality and reduce diversity within the habitat, affecting the structure and functions of reef communities. Due to the generally low tolerance of reef habitat to anthropogenic pressures the current status is assessed as 'Inadequate/Stable' (NPWS, 2019a). A table summarising the pressures and threats affecting each biogenic species and geogenic reef habitat is shown in Table 7.

Cold-water corals are particularly susceptible to anthropogenic impacts, principally those arising from fishing activities, however any form of physical disturbance can be damaging to these sensitive reef structures. Cold-water corals are long-lived, slow growing, and fragile, making them especially vulnerable to physical damage and as such they may take centuries to recover, if at all (Hall-Spencer & Stehfest, 2008; Glenn *et al.,* 2010).

Bivalve reefs are threatened habitats within Irish waters and are also highly affected by physical disturbance, particularly from fishing activities (Kasoar *et al.,* 2015). Bivalve reefs are more susceptible in the intertidal environment due to the additional impacts of eutrophication and increased storm disturbance. Mussels and oysters are also important fisheries in themselves, which adds an additional threat which other biogenic species are not affected by. Bivalves are however generally tolerant of chemical contaminants and pollution in the marine environment.

Polychaete reefs are generally more tolerant to the effects of climate change and to the impacts of contaminants and pollutants compared to other biogenic reef species (Fariñas-Franco *et al.,* 2014). However, they are still vulnerable to physical disturbance which can flatten reef structures due to their fragile nature. Depending upon the amount of damage to the reef, recovery times can be relatively rapid compared to other longer-lived bivalve and coral habitats (OSPAR, 2009d).

Geogenic reef habitat is more largely affected by storm disturbance and the effects of eutrophication and pollution in the intertidal environment, which can lead to destabilisation of communities, the recovery of which can take upwards of 10 years (Hill *et al.,* 1998; JNCC, 2007). The effects of fishing activity in the intertidal zone is low, and although there is higher impact in the subtidal zone the effects are generally less than the impacts to biogenic reef structures and recoverability is typically faster.

Table 7 Summary of threats to biogenic and geogenic reef habitat including a ranking of the level of risk, based upon the evidence presented in the above sections. The ranking of level of risk takes into account the susceptibility of the species, its recoverability, and the likelihood that the threat will impact on the species.

Threat	***Sabellaria spinulosa***	***Sabellaria alveolata***	***Serpula vermicularis***	***Modiolus modiolus***	***Mytilus edulis***	***Ostrea edulis***	***Lophelia pertusa***	***Madrepora oculata***	**Geogenic reef habitat**
Fishing activities (all gear types)	High	High	High	High	High	High	Very High	Very High	Low
Infrastructure development	Medium	Medium	Medium	Medium - Low	Medium - High	Medium - High	High	High	Medium
Aggregate extraction	High	High	High	Medium	High	High	High	High	Low
Aquaculture and moorings	Medium	Medium	High	Medium	Low	Low	Low	Low	Low
Removal of species	Low	Low	Low	Low and local	Medium - High	Medium - High	Low	Low	Medium
Non-native species	Medium	Medium	Unknown	Unknown	High	High	Unknown	Unknown	High
Contaminants and pollution	Low	Low	Medium-Low	Medium	Medium	Medium	High	High	Medium
Eutrophication	Low	Low	Medium	Low and local	Low	Medium	Low	Low	High
Sedimentation/ smothering	Low	Low	Medium	Medium	Medium	Medium	Medium-High	Medium-High	Medium
Climate change: temperature change	Low	Low	Low	Medium-High	Low	Low	Low	Low	High

Threat	***Sabellaria spinulosa***	***Sabellaria alveolata***	***Serpula vermicularis***	***Modiolus modiolus***	***Mytilus edulis***	***Ostrea edulis***	***Lophelia pertusa***	***Madrepora oculata***	**Geogenic reef habitat**
Climate change: ocean acidification	Low	Low	Low	Medium	Medium-Low	Medium	High	High	Medium

5 Conservation Measures

In Ireland, the 1992 EC Habitats Directive (92/43/EEC) is currently the main legislation providing protection to specified habitats in the marine environment. Under this legislation, a network of Natura 2000 sites was created, where habitats for protection are identified and SACs designated for their protection, within which habitats must be maintained at favourable conservation status. Favourable conservation status is achieved by ensuring the national range, area, structure and functions of the habitats are not negatively affected. In order to protect habitats under the Habitats Directive, operations or activities proposed in or adjacent to SACs designated for listed features must demonstrate that they will not unfavourably affect the conservation status of the habitat (NPWS, 2024).

The conservation importance of biogenic and geogenic reefs, and their role in sustaining marine biodiversity is well recognised. The Habitats Directive allows protection of aggregating ecosystem engineered habitats such as biogenic and geogenic reef under Annex I Reef Habitat (Braeckman *et al.,* 2014). A list of reef-forming species afforded protection within Irish waters is provided in Table 8. It should be noted, however, that the legislative regulations outlined relate solely to reef habitats and not to solitary individuals or non-reef communities (Hendrick *et al.,* 2011). Forty-eight SACs have been designated for the protection of Annex I Reef habitat within Irish waters, their extent is shown in Figure 8 and Figure 9, and a list of the SACs and their extent is provided in Appendix 2. In recent years, significant levels of survey work have been undertaken to investigate the structure, distribution and extent of these reef habitats in Irish SACs. Following these surveys, a total of 2,204 km^2 of reef habitat is known to occur within SACs in Irish waters (NPWS, 2019).

In 1981, Lough Hyne was designated as a Nature Reserve in Ireland, under the Wildlife Act 1976. It is Irelands only Marine Reserve and is the only marine area in Ireland that is fully protected from any fishing pressure. Although mainly designated for Annex I Large shallow inlets and bays, Annex I Reefs are also present in the area, including intertidal and subtidal reef communities and *Laminaria*-dominated communities (NPWS, 2014).

Management and conservation of cold-water coral reef habitats has primarily focused on area closures. In 2006, within the Irish EEZ, the closure of four SACs, to all activities, was implemented in order to protect *L. pertusa* reef (Hall-Spencer & Stehfest, 2009; Glenn *et al.,* 2010; Armstrong *et al.,* 2014). The full extent of cold-water coral reef habitat within Irish waters is not fully known. Of the protected areas designated within Irish waters, it is believed they currently protect 12.5% of predicted suitable habitat for *L. pertusa* reef (Ross & Howell, 2013). Therefore, the ability to assess habitat extent can be an important tool in marine conservation efforts, and this is especially true for cold-water coral reef.

Table 8 List of species and habitats afforded protection within Irish waters

Protection Mechanism	Habitat
EC Habitats Directive	Habitats specifically included under the Annex I Reefs (1170) habitat. • *Lophelia pertusa* • *Madrepora oculata* • *Sabellaria alveolata* • *Sabellaria spinulosa* • *Serpula vermicularis* • *Mytilus edulis* • *Modiolus modiolus*

Protection Mechanism	Habitat
OSPAR	The OSPAR list of priority habitats include: • Coral gardens • Deep-sea sponge aggregations • *Lophelia pertusa* reef • *Modiolus modiolus* Horse Mussel beds • Intertidal *Mytilus edulis* beds on mixed and sandy sediments • *Ostrea edulis* beds • *Sabellaria spinulosa* reef

In 2000, the Irish Coral Reef Task Force was formed to liaise with the relevant Irish Government Agencies with the goal of co-ordinating additional data gathering on coral distribution and fishing activity, establishing whether Irish coral reefs are being damaged and formulating conservation policy for the protection of corals in Irish waters. The Irish Coral Task Force supplements the work of the EU Atlantic Coral Ecosystem Study at a national level and its main objectives are to determine the level of impacts from fishing on coral reefs in Irish waters, to identify the appropriate legal instruments for use in implementing conservation measures to protect corals in Irish waters, and to liaise with relevant policy makers and managers (Grehan *et al*., 2003; Wattage *et al.,* 2011).

In order to further protect reef habitats within Irish waters, a number of mitigation measures can be implemented. For example, risk of damage to habitats can be minimised before infrastructure development, such as wind farms, oil and gas rigs, trenching and pipe/cable-laying, provided proper Environmental Impact Assessments are undertaken before developments begin (OSPAR 2009c). Habitat Regulations Assessments can also be undertaken for activities proposed to have an impact near to an SAC or protected reef habitat. The loss of reef habitat resulting from aquaculture activities, moorings, and waste discharge can also be mitigated through reef enhancement programmes involving the deployment of suitable substrata or re-seeding of reef species (Chapman *et al.,* 2007).

The development of the Integrated Marine Plan (IMP) for Ireland in 2012 could also be a useful tool to aid in the conservation of reef habitat. The IMP is designed to ‘strike a balance between protecting our marine environment (and its species and habitats) and maximising the use of its resources as a source of economic growth’ (Marine Institute Ireland, 2012). If reef location and distribution are considered during development of the marine plan, then they may help in conserving reef habitat.

Management initiatives for individual reef-forming species have also been implemented in Ireland for the protection of reef habitats. For example, with only 15% of the world’s oyster reef habitat left, substantial efforts are underway to protect and restore the remaining reef habitat (Grabowski *et al*., 2012). Useful management measures include continued fishery regulation, control of the spread of non-native species and maintenance of a suitable habitat to support successful spatfall (OSPAR, 2009c). In Ireland, a number of oyster beds occur within the Natura 2000 network, and harvesting of these stocks is subject to appropriate assessment, as required by the Habitats Directive. The Shellfish Waters Directive provides further protection for bivalves, by improving areas designated for shellfish production, including production areas for *O. edulis*.

In Ireland, designated shellfish waters are strongly supported by the oyster fishermen who are proactive in the management of potential pollution (OSPAR, 2009c). Local management groups are also proactive in protecting oyster beds, using a range of management measures, including seasonal fishing, season and daily quotas, and minimum landing sizes.

Other management measures in Ireland have included the collection of spat for re-seeding previously known beds and other suitable areas (*e.g*. Tralee Bay) and translocation of reef-forming bivalves to more suitable habitats, in order to increase abundances in Irish waters

(OSPAR, 2009c). This technique has also been used successfully for restoring and enhancing populations of *M. modiolus* within Strangford Lough, Northern Ireland (Strain *et al.,* 2012).

Despite the implementation of protected areas to enhance reef habitat there is still a great deal of uncertainty regarding the distribution and prevalence of reef habitats within Irish waters. This is partly due to the difficulty in deciding what constitutes ‘reef’ as opposed to a ‘non-reef’ habitat, although greater clarity in this distinction has been achieved for Ross Worm colonies in recent years. Further work is still needed in this respect for both Blue and Horse Mussel colonies (Hendrick *et al.,* 2011).

The designation of SACs are potentially the most effective means of addressing the threat to biogenic and geogenic reef, by enabling the conservation and protection of reef habitats. Other future conservation measures which may aid in the protection of reef habitats is the implementation of marine reserves, such as the one at Lough Hyne, which restrict fishing or other activities in areas of reef habitat. Other management measures such as seasonal fisheries closures or gear restrictions in areas of reef habitats may also prevent destruction of reef habitat. Seasonal or temporary closures may be particularly effective for the protection of *Sabellaria* reefs, which due to their ephemeral nature, may develop in an area and need short-term protection.

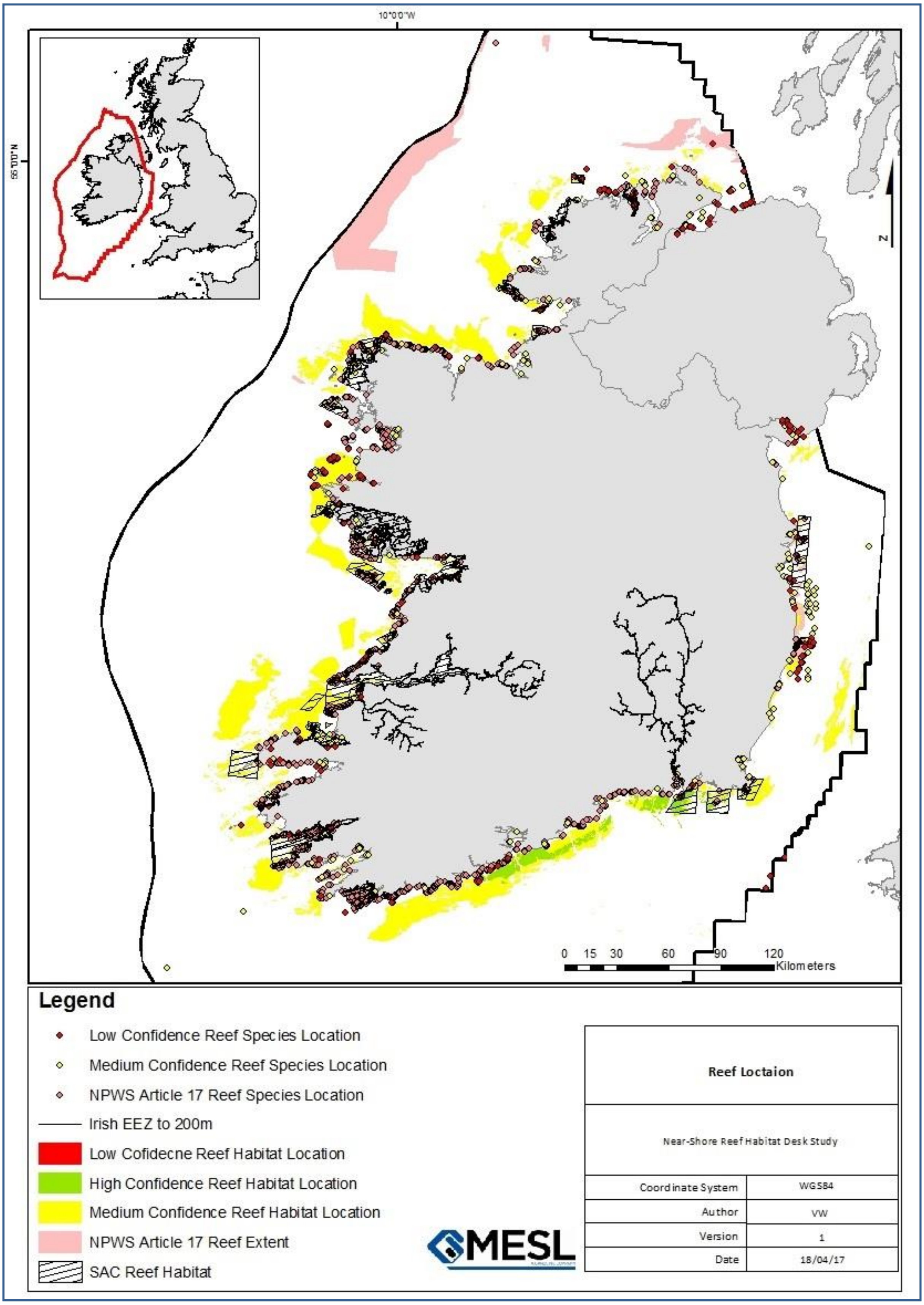

Figure 8 Location of SACs designated for the presence of reef habitat in Irish near-shore waters to 200 m with the assigned confidence assessment of each reef data layer.

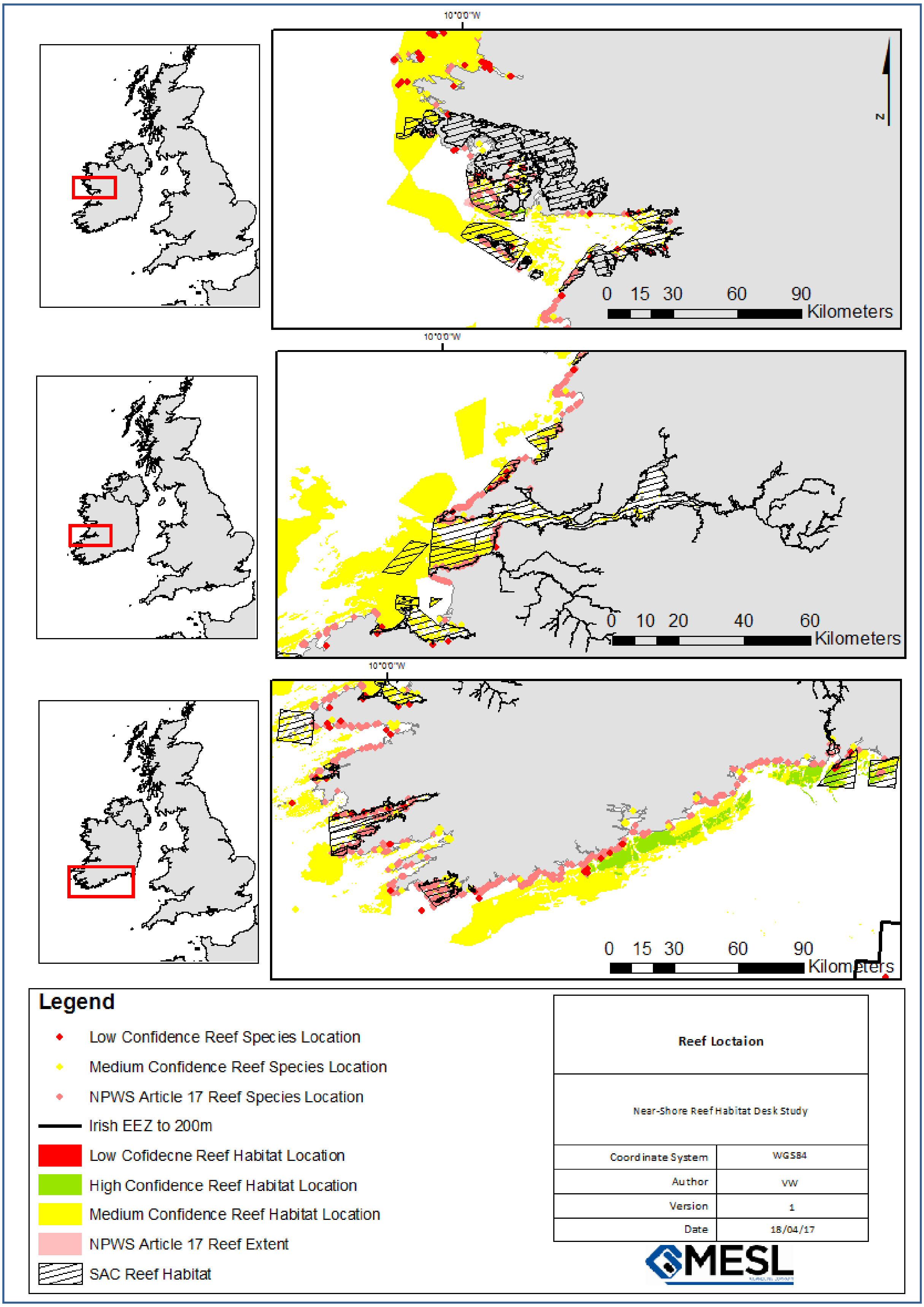

Figure 9 Zoomed in view of the location of SACs designated for the presence of reef habitat in Irish near-shore waters to 200 m with the assigned confidence assessment of each reef data layer.

6 Conclusion

Reef habitats, both biogenic and geogenic, are highly important marine habitats, noted for their important structural role in coastal areas, ability to enhance the diversity and abundance of marine fauna, ability to increase habitat complexity and create opportunities for ecological interactions. The current status of reef habitat within the Irish EEZ is assessed as Inadequate/Stable primarily due to poor future prospects of structure and function, as a result of the low tolerance of reef habitat to physical disturbance (NPWS, 2019a).

As such the aim of this project was to improve the knowledge of the structure, functions and distribution of habitats and communities containing potential Annex I reef habitat, within Irish near-shore waters, to a depth of 200 m. In doing so, the project aimed to provide a more comprehensive understanding of the location of reef habitat within Irish near-shore waters, in order to improve future management and to enable a more robust assessment of conservation status, by improving the knowledge of all four areas of assessment: range, area, structure and functions, and future prospects.

Reef can be broadly categorised into biogenic or geogenic reef based on their form. They are described as “hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone and may support a zonation of benthic communities of algae and animal species”. Geogenic reefs are defined by the substratum rather than by a specific biological community, and as such the range of these habitats is determined by physical and geological processes. As a result, rocky reefs are extremely variable, both in structure and in the communities they support. Biogenic reefs are defined by the presence of a structure created by organisms themselves. The main biogenic reef-forming species present in Irish near-shore waters are *Sabellaria alveolata, Sabellaria spinulosa, Serpula vermicularis, Mytilus edulis, Modiolus modiolus, Ostrea edulis, Limaria hians, Lophelia pertusa* and *Madrepora oculata.*

Reef habitats in Irish waters range from the intertidal zone to 4500 m below the sea surface and more than 400 km from the coast. There are a number of physical and environmental factors that control the distribution of this habitat type including tidal immersion and wave exposure, freshwater influences, fluctuations in temperature, and desiccation. Reef habitats can therefore proliferate across a wide range of environmental gradients; however, each reef type requires certain environmental conditions. Many reef-building species form extremely variable community types, with no obvious gradation between non-reef and reef biotopes. Predicting their exact range is therefore more difficult, partly due to the difficulty in deciding what constitutes ‘reef’ as opposed to a ‘non-reef’ habitat. Although greater clarity in this distinction has been achieved for *Sabellaria* reef habitat in recent years, further work is still needed for both Blue and Horse Mussel colonies.

Overall reef habitats create structures that reach into the water column from the seafloor, creating important habitats for a variety of marine organisms, and providing a range of positive effects for the surrounding environment. Typically, they provide an increase in structural complexity and a cryptic habitat which allows for the settlement of other species and provides refuge from predation, competition, and physical and chemical stresses. Reef habitats may also represent important food resources, providing food for juvenile fish and economically important fish stocks, as well as providing areas for foraging, refuge and nursery grounds.

Cold-water reefs are also of significant ecological and economic value, and offer an extensive list of ecosystem services including acting as suppliers of goods and services for increased biodiversity, pharmaceutical compounds, as a sink for CO_2 sequestration, and for fisheries.

Bivalve reefs, *Mytilus, Modiolus* and *Ostrea*, have been shown to provide a wide range of ecosystem services including shoreline protection, provisioning, and influence on nutrient cycling. Additionally, their structured habitat can provide areas for juvenile fish species and nursery grounds for other marine organisms. In addition to this, as filter feeders, bivalve reefs are able to maintain and regulate habitats, to a certain extent, by counteracting increases in anthropogenic nitrogen in the water column. By filtering large quantities of water, they promote denitrification and simultaneous reductions in pollution, and act to increase water clarity.

As with the other reef-forming species, polychaete worm reefs often support a diverse flora and fauna and have been shown to play an important role in increasing stability and structural composition of the seabed and are important feeding grounds for many marine species. In addition, the structures they create modify the hydrodynamic flow regime near the sea floor. This plays an important role in the ecosystem by altering water flow, reducing wave energy and has potentially significant ecological effects on sedimentation patterns, food availability, larval and/or juvenile recruitment, growth, and survival.

Geogenic reefs are also important ecological features and are well noted for their high levels of biodiversity, especially compared to surrounding sedimentary habitats. In the infralittoral zone, kelp forests are some of the most ecologically dynamic and biologically diverse habitats. They provide habitat for other marine species by increasing habitat complexity and provide substrata for other species to attach and settle. Kelp beds also have considerable conservation value, as they are the major primary producers in temperate marine coastal habitats. In the rocky subtidal zone, sponge and hydroid communities can provide enhanced food supply in feeding currents, and act as potential food source themselves. They are also important nursery areas for many commercially important species of fish including herring, cod, and hake.

In Irish waters, the overall extent of reef habitat was calculated at 9,474 km^2 in this project compared to the previous extent calculated at 9,146 km^2 based on data collected during the 2013 Article 17 reporting. It should be noted that this figure does not take the confidence assessment into account. Three newly documented areas of reef habitat were found during the present study, indicating increased records of reef habitat, especially in areas around the coastline. Of the newly defined areas, there was a mix of both biogenic and geogenic reef, which shows diversity within the habitats.

Using information gathered during the literature review, indicators to aid in evaluating the structure and functions of reef habitat have been suggested. These are based on biological, chemical, and physical attributes important for regulating the establishment of reef habitats. These indicators may be useful for future monitoring as they may aid in assessing reef distribution, reef structure, and reef function within Irish waters.

In Ireland, the 1992 EC Habitats Directive (92/43/EEC) is currently the main legislation providing protection to specified habitats in the marine environment, including reef habitats. Under this legislation, a network of Natura 2000 sites was created, where habitats for protection are identified and Special Areas of Conservation (SACs) designated for their protection. Forty-eight SACs have been designated for the protection of Annex I Reef habitat within Irish waters. In recent years, significant levels of survey work have been undertaken to investigate the structure, distribution and extent of these reef habitats in Irish SACs. Following these surveys, a total of 2,204 km^2 of reef habitat is known to occur within SACs in Irish waters (NPWS, 2019a).

The resilience or recoverability of some reef habitats, particularly offshore rocky and cold-water coral reefs, is low. Even small levels of pressure, particularly from fishing or physical disturbance, have the potential to affect ecological quality and reduce diversity within the habitat, due to the loss of reef structure or reduced function.

In order to improve the management and protection of reef habitats, future work should prioritise investigations of how ecological processes in coastal ecosystems respond to extreme events and which features may determine their resilience and recovery. A more thorough understanding of anthropogenic impacts to species within different habitats is also needed to fully understand the effects of disturbance to biogenic and geogenic reef. A clear understanding of the environmental requirements for reef proliferation is also essential for determining reef location and for future conservation of reef habitats.

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8 Appendices

Appendix 1 List of data layers, with brief descriptions, sourced and included in the mapping of reef habitat distribution. Data layers can be seen displayed in Figure 1.

Data Layer	Description	Source	Confidence
EUNIS habitats	Polygon data showing the distribution of subtidal reef habitats around Ireland	ISDE	Medium
Celtic Sea Nearshore Habitats	Polygon data showing reef habitat, collected as part of the MESH Atlantic project	ISDE	High
Cork Coastal Rock Habitats	Polygon data showing reef habitat, collected as part of the MESH Atlantic project	ISDE	High
South Irish Sea Habitats	Polygon data showing reef habitat, collected as part of the MESH Atlantic project	ISDE	Medium
North Irish Sea Habitats	Polygon data showing reef habitat, collected as part of the MESH Atlantic project	ISDE	Medium
Belmullet Marine Habitats	Polygon data showing EUNIS habitat classifications of seabed habitat, collected as part of the INFORMAR project	ISDE	Medium
Northwest Ireland Seabed Habitats	Polygon data showing EUNIS habitat classifications of seabed habitat, collected as part of the INFORMAR project	ISDE	Medium
Southwest Ireland Seabed Habitats	Polygon data showing EUNIS habitat classifications of seabed habitat, collected as part of the INFORMAR project	ISDE	Medium
OSPAR Habitats	Point and polygon data showing a list of threatened and/or declining species and habitats.	EMODnet	Medium
GB000681 - Map of offshore benthic communities of the Irish Sea	Polygon data showing EUNIS habitat classifications of seabed habitat	EMODnet	Medium
GB001117 – Croker Carbonate Slabs, Mid-Irish Sea	This is a composite map of EUNIS-classified habitat in UK waters	EMODnet	Medium
GB001503 – Broadscale habitat (Eunis level 3) for the St Georges Channel recommended marine conservation zone (rMCZ)	Polygon data depicting broadscale habitat features at the Mid St George's Channel	EMODnet	High
IE000009: Blacksod Bay seabed habitat data	Polygon data showing seafloor habitat data for Blacksod Bay	EMODnet	Medium

Data Layer	Description	Source	Confidence
IE000010: Broadhaven Bay seabed habitat data	Polygon data showing seafloor habitat data for Broadhaven Bay	EMODnet	Medium
IE000113: County Dublin coastal habitat zones	Polygon data from Intertidal & subtidal biotope field surveys	EMODnet	Low
IE000114: Broad scale biotope types around Dublin coast	Polygon data from Intertidal & subtidal biotope field surveys	EMODnet	Medium
IE000115: County Wexford coastal habitat zones	Polygon data from Intertidal & subtidal biotope field surveys	EMODnet	Medium
IE000116: Broad scale biotope types along Wexford coast	Broad scale biotope types along Wexford coast mapped out to the 5 km limit	EMODnet	Medium
IE000117: County Wicklow coastal habitat zones, east coast Ireland	Polygon data from Intertidal & subtidal biotope field surveys	EMODnet	Medium
IE000118: Broad scale biotope types along Wicklow coast	Broad scale biotope types along Wicklow coast mapped out to the 5 km limit	EMODnet	Medium
IE000980: West Malin Head habitat map (Area A)	Polygon data showing seafloor habitat data for wet of Marlin Head	EMODnet	Medium
IE000981: West Malin Head habitat map (Area B)	Polygon data showing seafloor habitat data for wet of Marlin Head	EMODnet	Medium
IE001000: Clew Bay Marine Habitats	Polygon data showing classification of Clew Bay marine habitats as part of the MESH Atlantic project	EMODnet	High
IE001001: Kilkieran Bay Marine Habitats	Polygon data showing classification of Kilkieran Bay marine habitats as part of the MESH Atlantic project	EMODnet	High
IE001002: Kenmare River Infralittoral Habitats	Polygon data showing classification of Kenmare Bay marine habitats as part of the MESH Atlantic project	EMODnet	High
IE001003: Roaringwater Bay Marine Habitats	Polygon data showing classification of Roaringwater Bay marine habitats as part of the MESH Atlantic project	EMODnet	High
IE001013: Valentia Island Marine Habitats	Polygon data showing classification of Valentia Island marine habitats as part of the MESH Atlantic project	EMODnet	Medium
IE001014: Kenmare River SAC EUNIS Habitat Map	Polygon data from seabed sampling as part of the MESH Atlantic survey	EMODnet	Medium

Data Layer	Description	Source	Confidence
EU Seamap 2016 - Broad-Scale Predictive Habitat Map	EUNIS classification from broad-scale habitat mapping.	EMODnet	Medium
Celtic Sea Species Data	Point data from species surveys	EMODnet	Medium
Collated Seabed Substrate Irish Continental Shelf	Polygon data from seabed sampling as part of the INFOMAR and INSS national seabed mapping programme	Marine Institute	Medium
Seabed Habitats	Polygon data mapped as part of EU Sea Map broad-scale physical habitat map for European Seas	Irelands Marine Atlas	Medium
Irelands Marine Atlas Predominant Habitat Type	Polygon data for the predominant habitat typologies,	Irelands Marine Atlas	Medium
Coastal and Marine Species	Point data of marine and coastal records of different taxonomic groups submitted to the National Biodiversity Data Centre	National Biodiversity Centre	Medium
BioMar Survey of Ireland	A database of marine species of the seashore and seabed of the island of Ireland	National Biodiversity Centre	Medium
Sabellaria spinulosa	Point data showing field observations of *Sabellaria spinulosa*	NBN	Low
Sabellaria alveolata	Point data showing field observations of *Sabellaria alveolata*	NBN	Low
Modiolus modiolus	Point data showing field observations of *Modiolus modiolus*	NBN	Low
Lophelia pertusa	Point data showing field observations of *Lophelia pertusa*	NBN	Medium
Limaria hians	Point data showing field observations of *Limaria hians*	NBN	Low
Serpula vermicularis	Point data showing field observations of *Serpula vermicularis*	NBN	Low
Ostrea edulis	Point data showing field observations of *Ostrea edulis*	NBN	Low
Mytilus edulis	Point data showing field observations of *Mytilus edulis*	NBN	Low
Seasearch Ireland	Point data from species surveys	OBIS	Medium
Seasearch Marine Surveys	Point data from species surveys	OBIS	Low
BioMar5 HABMAP	Point data from species surveys	OBIS	Medium
Site Specific Conservation Objectives for EU Annex 1 Habitats	Polygon data defining Habitats Directive Annex I habitats	Data.gov.ie	Medium

Data Layer	Description	Source	Confidence
NPWS Article 17 Reporting Ireland SAC	Polygon and point data showing extent of reef habitat during the 2013 article 17 reporting	NPWS	Confidence not assigned – Existing extent as defined by NPWS
Ireland SAC	Locations of SAC's in Irish waters	NPWS	-

Appendix 2 Special Areas of Conservation within Irish waters designated for Annex I reef habitat. Known reef area indicates the known area of reef habitat within each SAC (Source: NPWS, 2023).

SAC Name	Location	Date Designated	Area km^2	Known reef area km^2
Black Head-Poulsallagh Complex	Onshore	2002	78	5.4
Lough Hyne Nature Reserve and Environs	Onshore	1998	5	0.9
Roaringwater Bay and Islands	Onshore	2002	143	35.0
Rathlin O'Birne Island	Onshore	2002	8	58.4
Slieve League	Onshore	2002	39	6.2
St. John's Point	Onshore	1997	11	8.7
Lambay Island	Onshore	2002	4	0.6
Inishmaan Island	Onshore	1997	8	0.7
Inishmore Island	Onshore	2002	147	63.3
Galway Bay Complex	Onshore	1999	144	27.7
Slyne Head Islands	Onshore	2002	24	14.2
Mullet/Blacksod Bay Complex	Onshore	1999	140	15.3
Broadhaven Bay	Onshore	2002	91	11.0
Bunduff Lough and Machair/Trawalua/Mullaghmore	Onshore	1999	44	12.0
Lady's Island Lake	Onshore	1999	5	0.1
Saltee Islands	Onshore	2002	158	46.0
Hook Head	Onshore	2002	169	105.3
Carrowmore Point to Spanish Point and Islands	Onshore	2002	42	28.3
Gweedore Bay and Islands	Onshore	2001	60	3.7

SAC Name	Location	Date Designated	Area km^2	Known reef area km^2
Inisheer Island	Onshore	1997	6	0.7
Connemara Bog Complex	Onshore	1997	492	0.1
Tralee Bay and Magharees Peninsula, West to Cloghane	Onshore	2002	116	28.6
Slyne Head Peninsula	Onshore	2002	40	5.7
Kilkieran Bay and Islands	Onshore	2002	214	90.8
Kenmare River	Onshore	2001	433	92.0
Mulroy Bay	Onshore	2001	32	0.4
River Barrow and River Nore	Onshore	2002	124	1.2
Lower River Shannon	Onshore	2002	683	214.2
Blasket Islands	Onshore	2001	227	48.6
Carrowmore Dunes	Onshore	2002	4	2.1
Tory Island Coast	Onshore	2002	30	20.7
Magharee Islands	Onshore	2002	23	22.4
Valencia Harbour/Portmagee Channel	Onshore	2002	27	9.5
Kerry Head Shoal	Inshore	2002	58	58.0
Kilkee Reefs	Onshore	2001	29	23.9
Achill Head	Onshore	2000	72	35.6
Carnsore Point	Onshore	2002	87	18.5
Wicklow Reef	Inshore	2001	15	15.3
Rutland Island and Sound	Onshore	2001	39	7.1
Rockabill to Dalkey Island	Onshore	2011	273	13.7
Porcupine Bank Canyon	Offshore	2012	781	78.6
South East Rockall Bank	Onshore	2011	1,488	149.3
Northwest-Porcupine Bank	Offshore	2009	716	0
Southwest-Porcupine Bank	Offshore	2009	329	0

SAC Name	Location	Date Designated	Area km^2	Known reef area km^2
Hovland Mound	Offshore	2009	1,086	0
Belgica Mound	Offshore	2009	411	0
Porcupine Shelf	Offshore	2023	14794.42	
Southern Canyons	Offshore	2023	14,434.29	

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