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Avoidance and Mitigation of Coral and Sponge Species During Exploratory Drilling Activities Offshore Newfoundland and Labrador

L. Gullage, V. Hayes, B.M. Neves, N. Wells, F. Cyr, and F.J. Murillo

Science Branch
Fisheries and Oceans Canada
PO Box 5667
St. John’s, NL A1C 5X1

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

An investigation was conducted into the likely impacts of exploratory drilling to coral and sponge species in the Newfoundland and Labrador (NL) region, as well as the ways in which avoidance and mitigation measures can be applied to reduce them. Impacts described in existing literature suggest that coral and sponge species may experience changes in behaviour (e.g. feeding, reproduction), fitness, and survival as a result of physical damage, exposure to chemicals, and/or excess sedimentation which result from exploratory drilling activities. As outlined in the *Fisheries Act,* it is recommended that a “mitigation hierarchy” of: (1) avoid, (2) mitigate, (3) offset, be used to reduce risks to biodiversity. However, because offsetting impacts would not generally be compatible with benthic conservation objectives, they are not discussed in depth in this report. Following this hierarchy, the avoidance of exploratory drilling in existing special areas that have been previously delineated based on the presence of coral and/or sponge species in high densities is essential for preserving biodiversity in the region. This would include Significant Benthic Areas (SiBAs), Vulnerable Marine Ecosystems (VMEs), and any sites where the zone of influence from exploratory drilling would overlap SiBA or VME boundaries. Avoidance in areas outside SiBAs and VMEs where the density of coral and sponge species observed during pre-drill surveys meets the thresholds used to define SiBAs and VMEs is also of high importance. In addition, various modifications to existing exploratory drilling processes, intended to mitigate the impacts to coral and sponge species, without considerations to engineering and/or economic impacts, have also been outlined within the report. They would allow for reductions to the area of impact, the amount of cuttings generated, and the release of drilling muds into the environment, thereby reducing the overall impact to coral and sponge species in the area.

1. INTRODUCTION

The Fish and Fish Habitat Protection Program (FFHPP) of DFO evaluates and provides advice to proponents on proposed works, undertakings and activities (WUA) that may affect fish and fish habitat (DFO 2019a). Most available research on the impacts of exploratory drilling on corals has focused on impacts specific to large, reef-forming coral species such as *Lophelia pertusa* (now referred to as *Desmophyllum pertusum*) (Purser and Thomsen 2012, Bakke et al. 2013, Larsson et al. 2013), and mitigation thresholds outlined by the Canada-NL Offshore Petroleum Board (C-NLOPB) are primarily based on research outside of the Northwest Atlantic (DNV 2013). This document aims at building upon existing scientific advice on the mitigation of harmful impacts on corals and sponges during exploratory drilling programs in the NL region, by providing regionally specific information to support FFHPP in the development of best management practices to guide review processes moving forward.

In 2019, DFO Science provided national advice regarding the assessment of the effectiveness of mitigation measures in reducing the potential impacts of oil and gas exploration and production on areas with defined benthic conservation objectives (i.e. Marine Protected Areas (MPAs) and other effective area-based conservation measures (OECMs) (DFO 2019c). As part of this previous advice, it was recommended that oil and gas exploration and production activities within these areas should be managed with higher risk aversion. In a review of the Regional Assessment of Offshore Oil and Gas Exploratory Drilling East of NL (DFO 2020), DFO Science has since recommended that mitigations be applied in all areas that are deemed special by DFO and/or other international scientific organizations such as the Northwest Atlantic Fisheries Oganization (NAFO) (e.g. VMEs), SiBAs, Ecologically and Biologically Significant Areas (EBSAs) but are not currently protected by other management measures (DFO 2020).

With plans to expand exploratory drilling activities in the NL region, the potential exposure of corals and sponges to impacts is also expected to grow. The presence of these species is associated with heightened levels of biodiversity in the deep sea (Gilkinson and Edinger 2009, Baker et al. 2012), and impacts to their health have the potential to exhibit cascading effects (Pham et al. 2019). To inform future recommendations, this report aims to:

1. provide a summary of the coral and sponge species currently known in offshore NL;
2. describe exploratory drilling activities that have the potential to impact corals and sponges;
3. characterize the effects of exploratory drilling on coral and sponge species known to occur in the NL region;
4. define thresholds for implementing mitigation measures;
5. provide recommendations on the mitigation tools that are best suited for this region;
6. identify recommended methods for pre-drill surveys, drilling, monitoring, and follow-up for coral and sponges; and to
7. highlight areas where more research is needed.

Ultimately, this work is intended to guide the development of best management practices to support the conservation of coral and sponge species during oil and gas exploration activities in NL.

2. CORAL AND SPONGE SPECIES IN NEWFOUNDLAND AND LABRADOR

There are over 160 species of corals and sponges known to occur in the NL region. These species have been observed across the continental shelf, in troughs, valleys, and canyons, as well as along the shelf edge Wareham and Edinger 2007, Murillo et al. 2011, Baker et al. 2012, Murillo et al. 2012, Wareham Hayes et al. 2019). They exist in a variety of shapes and sizes, with some known to be found in high densities, while others are more sparsely distributed.

Throughout their range, these species represent complex, three-dimensional structures that can provide large- and small-scale habitats in the deep sea. Evidence suggests that they represent diversity hotspots (Kunzmann 1996, Klitgaard and Tendal 2004, Henry and Roberts 2007, Hogg et al. 2010, Beazley 2013a), with areas of high coral species richness positively correlated with areas of high fish species richness (Edinger et al. 2009, Komyakova et al. 2018). In the NL region, various species are known to associate with corals (Buhl-Mortensen and Mortensen 2004, Buhl-Mortensen and Mortensen 2005, Mortensen and Buhl-Mortensen 2005, Edinger et al. 2009, Baillon et al. 2012, Baillon et al. 2014, Hamel et al. 2015, Rooper et al. 2019) and sponges (Hogg et al. 2010, Kenchington et al. 2013, Rooper et al. 2019) (e.g. fish, crustaceans, molluscs, echinoderms, cnidarians, and polychaetes), using the large scale habitats they provide for feeding, resting, predator avoidance, or as nurseries for juvenile fish and invertebrates (Freese and Wing 2003, Ryer 2004, Auster 2005, Costello et al. 2005, Auster 2007, Amsler et al. 2009, Beazley et al. 2013a, Wareham Hayes et al. 2017, Neves et al. 2020). On a smaller scale, the skeleton, tissue, and mucus of some coral and sponge species also act as habitat for a diverse variety of bacteria (Schöttner et al. 2009, Hogg et al. 2010, Schöttner et al. 2013, Kennedy et al. 2014, Kellogg et al. 2016, Verhoeven et al. 2016, Verhoeven and Dufour 2017, Weiler et al. 2018).

Coral and sponge species play important roles in carbon processing and biogeochemical cycling in the deep sea (Pham et al. 2019, Pierrejean et al. 2020), with some describing the areas they occupy as hotspots for organic cycling (Cathalot et al. 2015). Research into sponge grounds on the Flemish Cap suggests that, through the removal of bacteria, uptake of ammonium (NH_4^+) and nitrite (NO_2^-), consumption of dissolved organic carbon (DOC), and production of nitrate (NO_3^-), these species act to enrich deep water ecosystems and promote primary productivity in upwelling areas (Pham et al. 2019).

In general, comprehensive information relating to life histories, reproduction, distribution, and sensitivities of individual coral and sponge species in the NL region is still limited. To account for this, species are often categorized into groups according to body size, shape, habitat preferences (i.e. substrate), and/or life history traits (Appendix B). In the absence of information at the species level, impacts at the group level can be more broadly applied to all species within a group. Similarly, because of limitations on the available information on the taxonomic diversity of sponges in the Northwest Atlantic, much of the information within this document is used to inform on sponges as a group. While it is recognized that these assumptions represent broad generalizations, this approach was considered necessary to compile enough information about the impacts of exploratory drilling for species which have otherwise been under-represented in the literature. For species that were deemed particularly important (e.g. habitat-forming species), or were well represented within the literature, information has been provided at the species level, where available.

2.1. SPECIES LIST

To ensure that a comprehensive inventory of coral and sponge species in the NL region was compiled, multiple data sources were used. The information was primarily drawn from the DFO-NL Research Vessel (RV) trawl survey database, but also included observations from the

Northern Shrimp Research Foundation (NSRF) survey, the Central and Arctic DFO RV trawl surveys, and any historic observations that have been documented. In addition, data collected as part of the EU-Spain Bottom Trawl Surveys, as well as literature published within the Northwest Atlantic Fisheries Organization (NAFO) Regulatory Area (NRA) was also incorporated to capture species observed beyond the Exclusive Economic Zone (EEZ). Independent observations were also included by conducting a comprehensive literature review for the region. All species mentioned in the literature have been documented in Appendix C, along with the source of the observation.

2.2. DISTRIBUTION

To illustrate the distribution of these species, multiple datasets were compiled. They include DFO RV trawl surveys performed in the NL (1995–2019) and Central and Arctic regions (2006–17), NSRF surveys (2005–18), as well as unpublished data from historical DFO research surveys (1948–94) which were conducted using various gear types (V.Hayes pers. comm.). Beyond the EEZ, much of the data came from EU-Spain Bottom Trawl Surveys (2002–13) conducted within the NRA, with some of these areas overlapping with DFO-NL RV trawl surveys in the region (e.g. 3LNO). To provide illustrations of coral and sponge distribution, these data were combined by group, input into ArcGIS 10.4 software (ESRI 2011), and mapped. Catch weights were displayed using graduated symbols with natural breaks to illustrate variations throughout the region. Only trawl sets where corals were present are shown. Distribution data is also discussed considering data from the literature and observations from opportunistic seafloor surveys (e.g. using imagery). The results are presented in Figure 2–Figure 9.

A few important caveats of the trawl data must be noted:

1. Observations are biased to locations where trawling is possible, meaning that there is limited knowledge about the distribution and biomass of species in more shallow waters, areas of hard substrates, vertical rock walls, and in waters deeper than 1,500 m.
2. Due to the nature of trawling, many of the specimens are damaged (e.g. fragmented) upon collection. As a result, reliable abundance and biomass records are challenging to obtain for some taxa (e.g. gorgonians).
3. There have been cases when specimens (including exceptionally large gorgonians) (Figure 1) have been captured in DFO-NL RV trawl survey sets that have been deemed unsuccessful because the gear performance was compromised (e.g. net damaged), and therefore not included in the RV survey database. In some cases, pictures or samples of these specimens were collected, but estimated weights for these specimens have not been incorporated into the distribution maps (Figure 2–Figure 9).
4. Data provided from EU-Spain Bottom Trawl Surveys beyond the Canadian EEZ only contain descriptions at the group level (large gorgonians, small gorgonians, sea pens, and sponges) for VME indicator species. Additionally, recent coral specimen identification has only been provided at the Class level (Class Anthozoa) for the NSRF survey, which takes place within domestic waters in NAFO Divisions 0B and 2G. As a result, comprehensive distribution data for these areas are restricted to the taxonomic levels that are reported. This does not mean that the other coral groups do not exist within these areas.

Figure 1: Large Paragorgia arborea *specimen from an unsuccessful 2019 DFO-NL RV trawl survey set in NAFO Division 3Ps.*

In general, and noting the above caveats, large gorgonians, small gorgonians, sea pens, cup corals, and black corals are largely distributed, in some cases discontinuously, along the edge of the continental shelf, and along the edges of channels and canyons found across the shelf (Figure 2 to Figure 4, Figure 6, Figure 7). Although direct comparisons to the distribution of cup corals and black corals were not possible based on the datasets used in this report, (Figure 6 and Figure 7), existing observations of cup corals and black corals beyond the EEZ (illustrated in Murillo et al. 2011) suggest that these species occupy similar ranges to gorgonians along the edge of the Flemish Cap. Contrastingly, soft corals (Figure 5), which can tolerate a large temperature range (Cimberg et al. 1981), exhibit a broader spatial distribution and are found across much of the continental shelf with a nearly continuous distribution along the shelf edge. Sponges (Figure 9) appear to exhibit a similarly broad range; however, it must be noted that sponges have not been identified to lower taxonomic levels, and that the distribution of specific sponge taxa is more restricted than is illustrated in Figure 9. Compared to the other groups, black corals have been observed less frequently in DFO-NL trawl surveys and are typically dominated by one species (*Stauropathes arctica*). When areas were explored beyond 1,500 m, the maximum depth of trawl survey gear, black coral diversity increased with five additional species documented, based on a 2010 remotely operated vehicle (ROV) survey of Flemish Cap and Orphan Knoll (V. Hayes pers. comm.).

The largest documented catches of large gorgonian corals (Figure 2) have occurred along the shelf edge (Northeast Saglek Bank) in the northern part of NAFO Division 2G. Smaller, but still substantial catches have also been observed within the Flemish Pass. Large catches of small gorgonian corals (Figure 3) are distributed more broadly along much of the edge of the southern Grand Bank, as well as portions of the shelf edge in NAFO Divisions 2GHJ3K. A small number have also occurred on the continental shelf throughout the region. Sea pen catch weights (Figure 4) exhibit a somewhat discontinuous pattern throughout the region, with many large catches observed in the Laurentian Channel, the southwest edge of the Grand Bank, throughout the Flemish Pass, and along the northern edge of the Flemish Cap. Sea pen communities can be dominated by different species in these areas, which range in size and weight (see Appendix C). Large catches of sea pens have also been documented along the shelf edge in NAFO Division 2G and in canyons on the shelf in Division 2H. Soft corals are the only coral group distributed throughout most of the region, including the continental shelf, edge, and slope. Soft coral catch weights (Figure 5) are largest along the eastern edge of the Grand Bank continuing north along the Flemish Pass, and Flemish Cap (Murillo et al. 2008), and into the southern edge of the Orphan Basin. Other large catches of soft corals have been identified along the shelf edge in division 2G as well as in areas such as in the southern portion of NAFO Division 2H (Hopedale Saddle). Documented catches of cup corals (Figure 6), which are found less frequently in DFO-NL trawl surveys, are largest along the southwest edge of the Grand Banks and include relatively large catches within the Laurentian Channel. There are a limited number of black coral observations in the NL region in the trawl database and therefore, the range of catch weights is quite small. As a result, catches defined as large are still small (1–6 kg) in comparison to the other groups described. Nonetheless, a limited number of large catches have been intermittently identified along the shelf edge in most NAFO Divisions. The largest of these are found in the northernmost portions of NAFO Division 2G as well as in the southern Flemish Pass (Figure 7). For corals that were not identified to the species or group level, large catch weights have been recorded along the shelf edge in NAFO Division 2G (likely large gorgonians), as well as in portions of 2J3KL (Figure 8). Documented sponge catches (Figure 9) are highest along the southeast shelf edge of the Grand Bank, moving north into the Flemish Pass and along the edge of the northern half of the Flemish Cap. Other large catches have been identified along the shelf edge in NAFO Divisions 2GJ3K. Catch weights for sponges are the highest of all groups, with a maximum catch of 12,000 kg reported from a single trawl set.

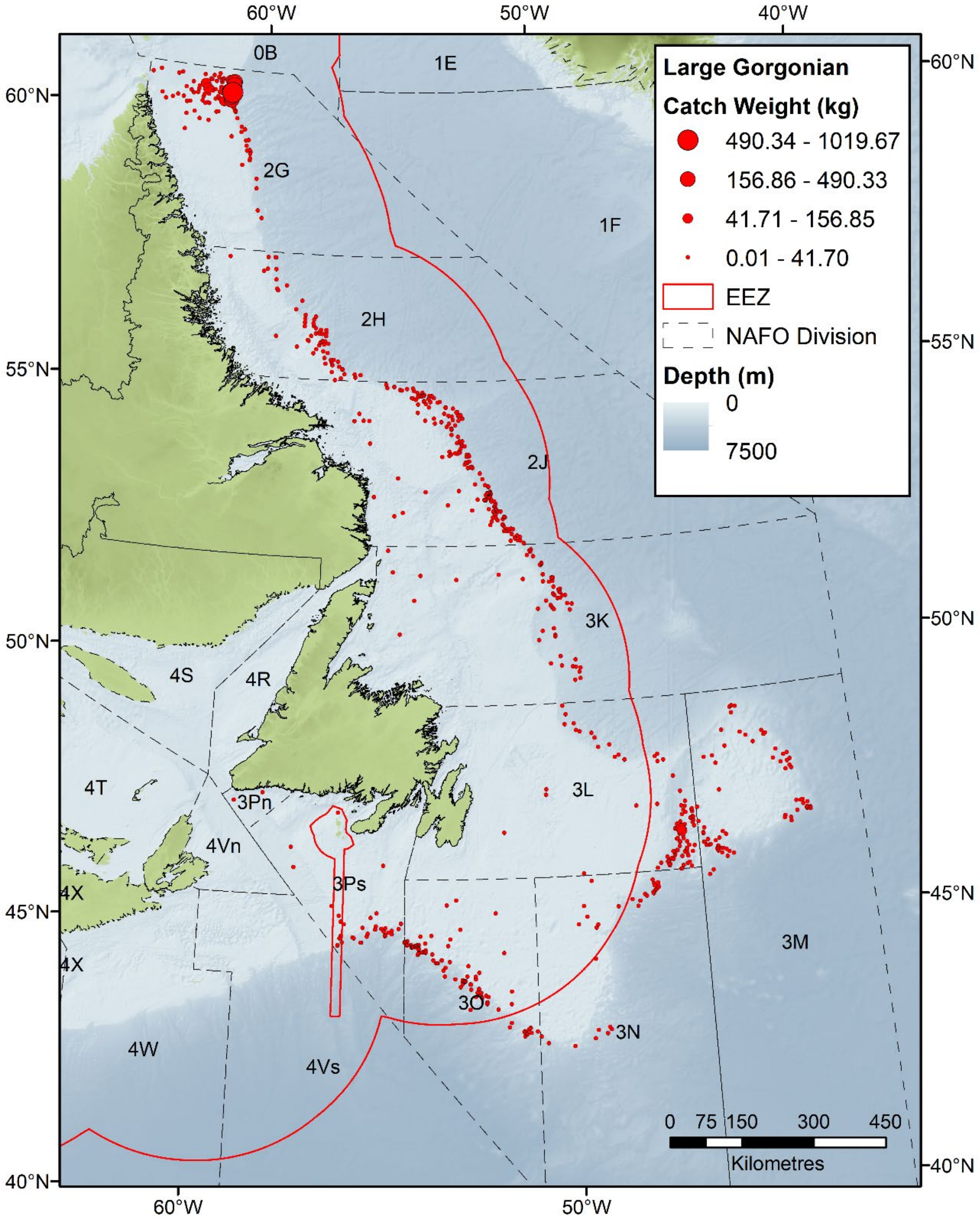


Figure 2: Distribution and catch weights of large gorgonian corals within the NL region.

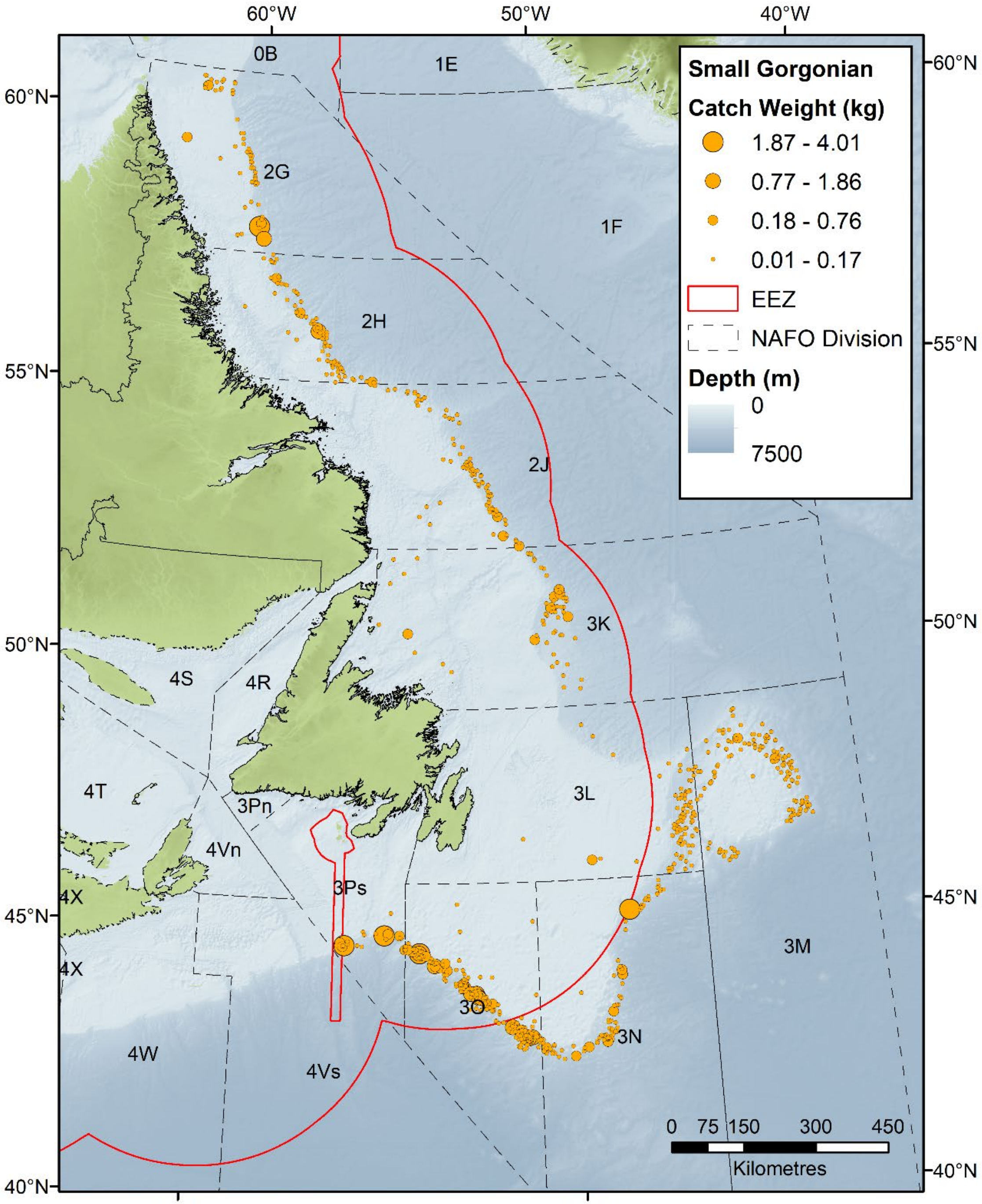


Figure 3: Distribution and catch weights of small gorgonian corals in the NL region.

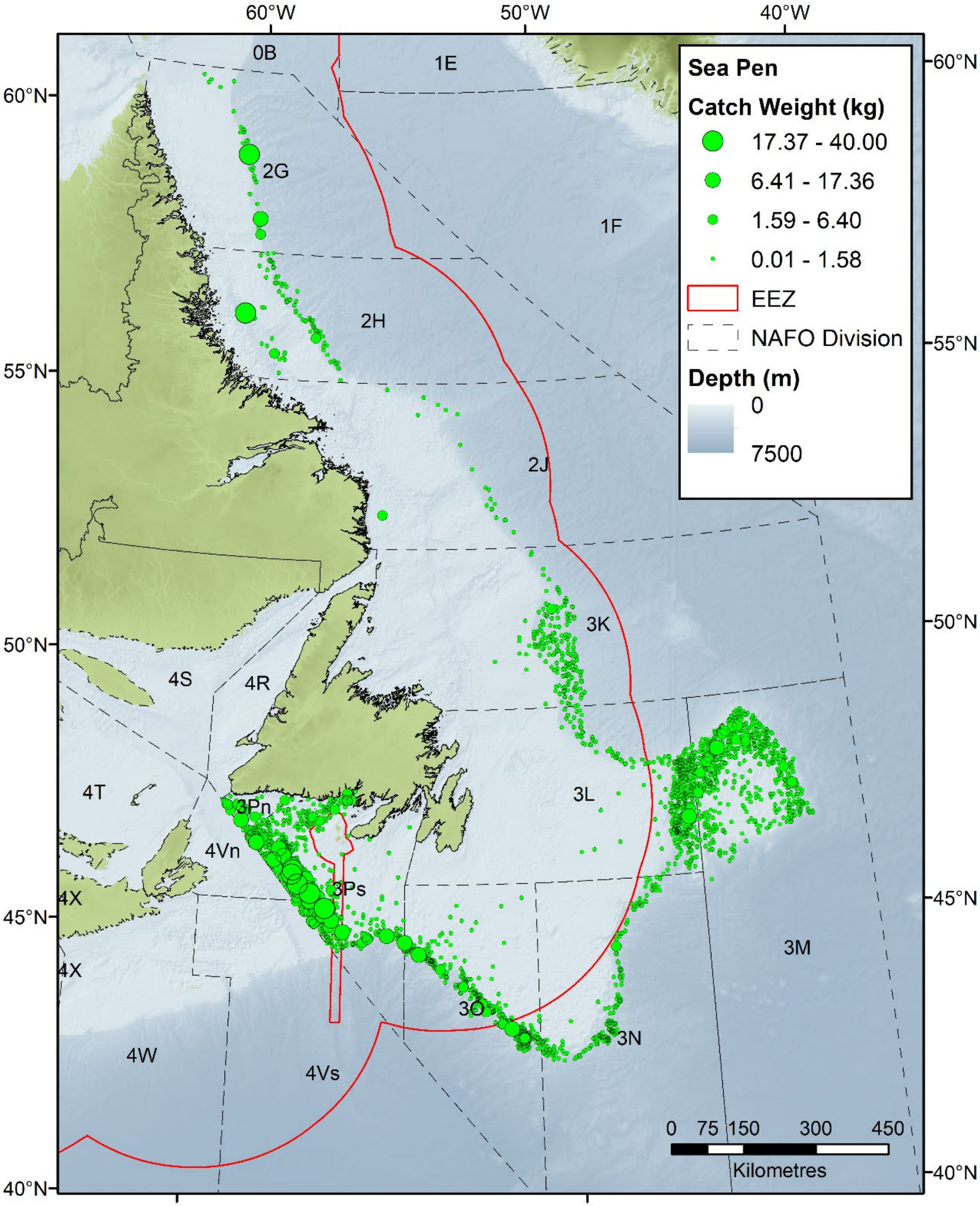


Figure 4: Distribution and catch weights of sea pen corals in the NL region.

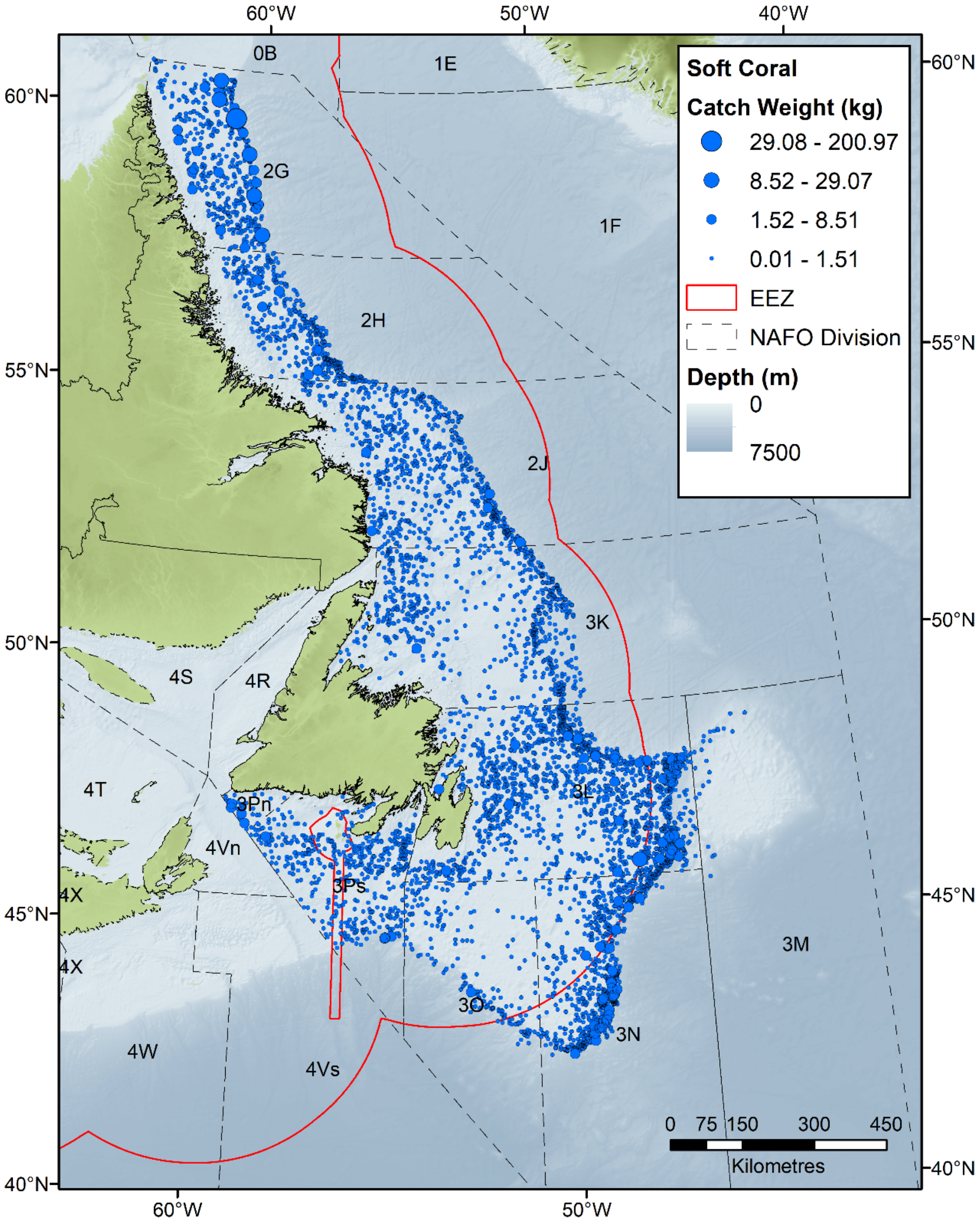


Figure 5: Distribution and catch weights of soft corals in the NL region.

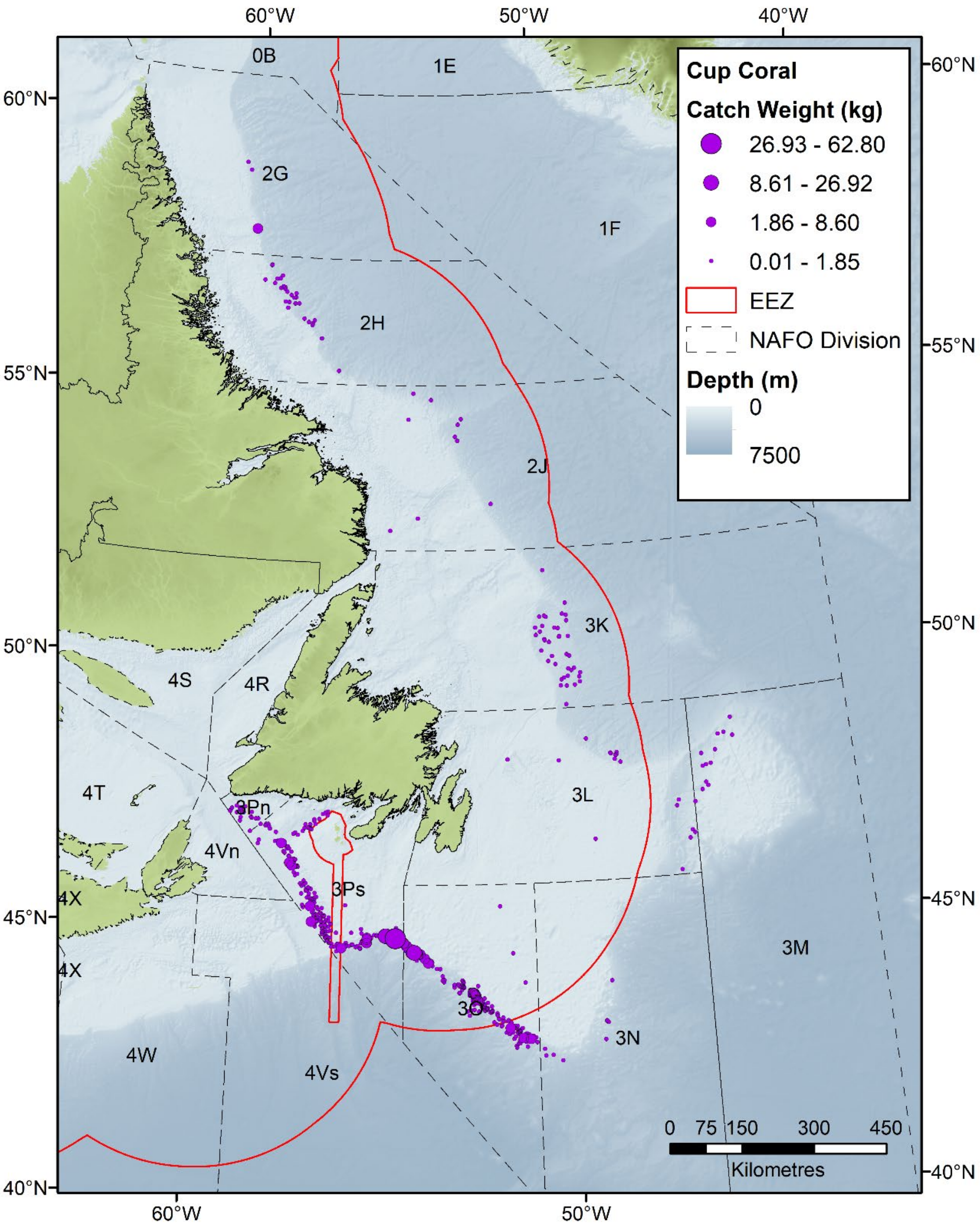


Figure 6: Distribution and catch weights of cup corals in the NL region.

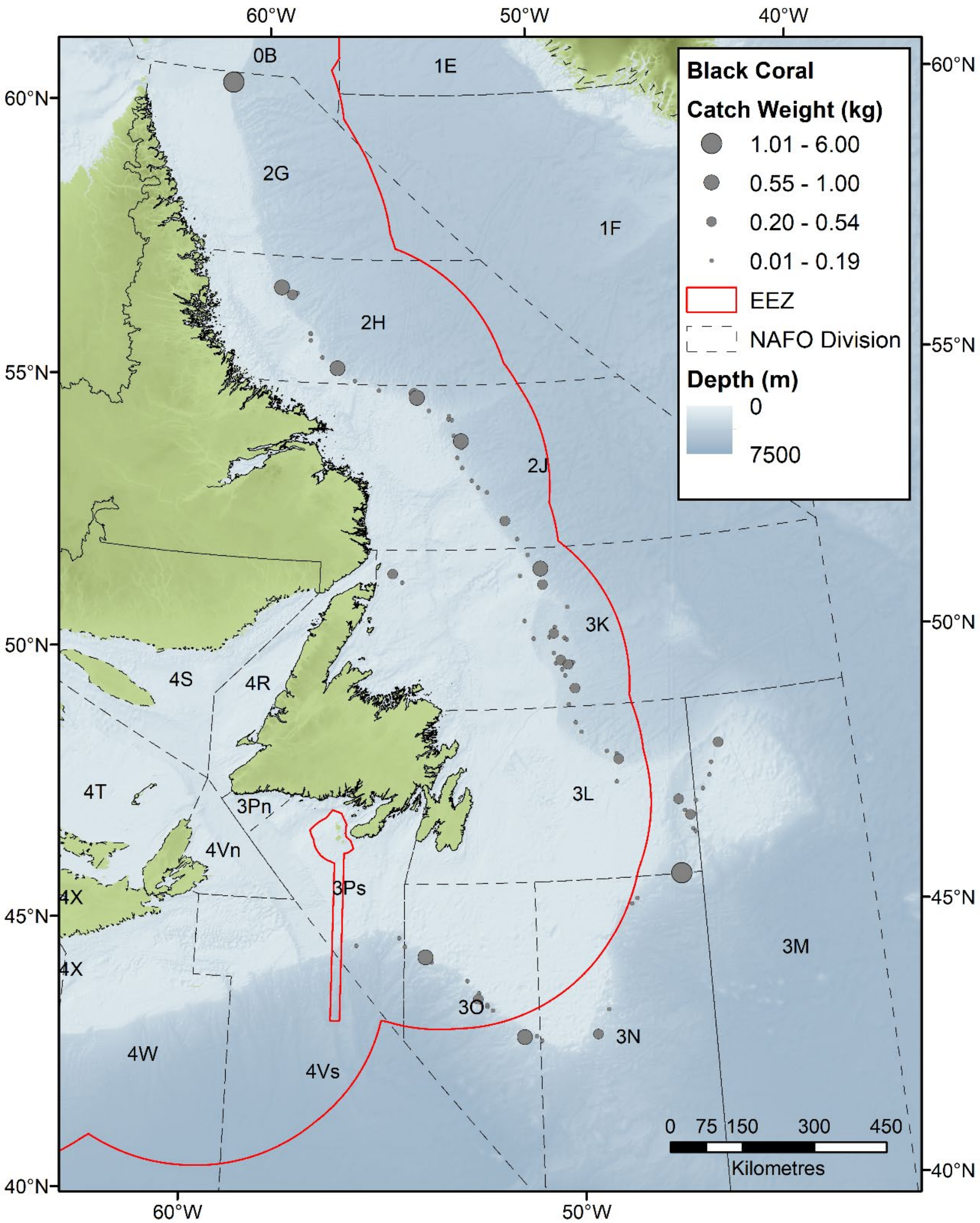


Figure 7: Distribution and catch weights of black corals in the NL region.

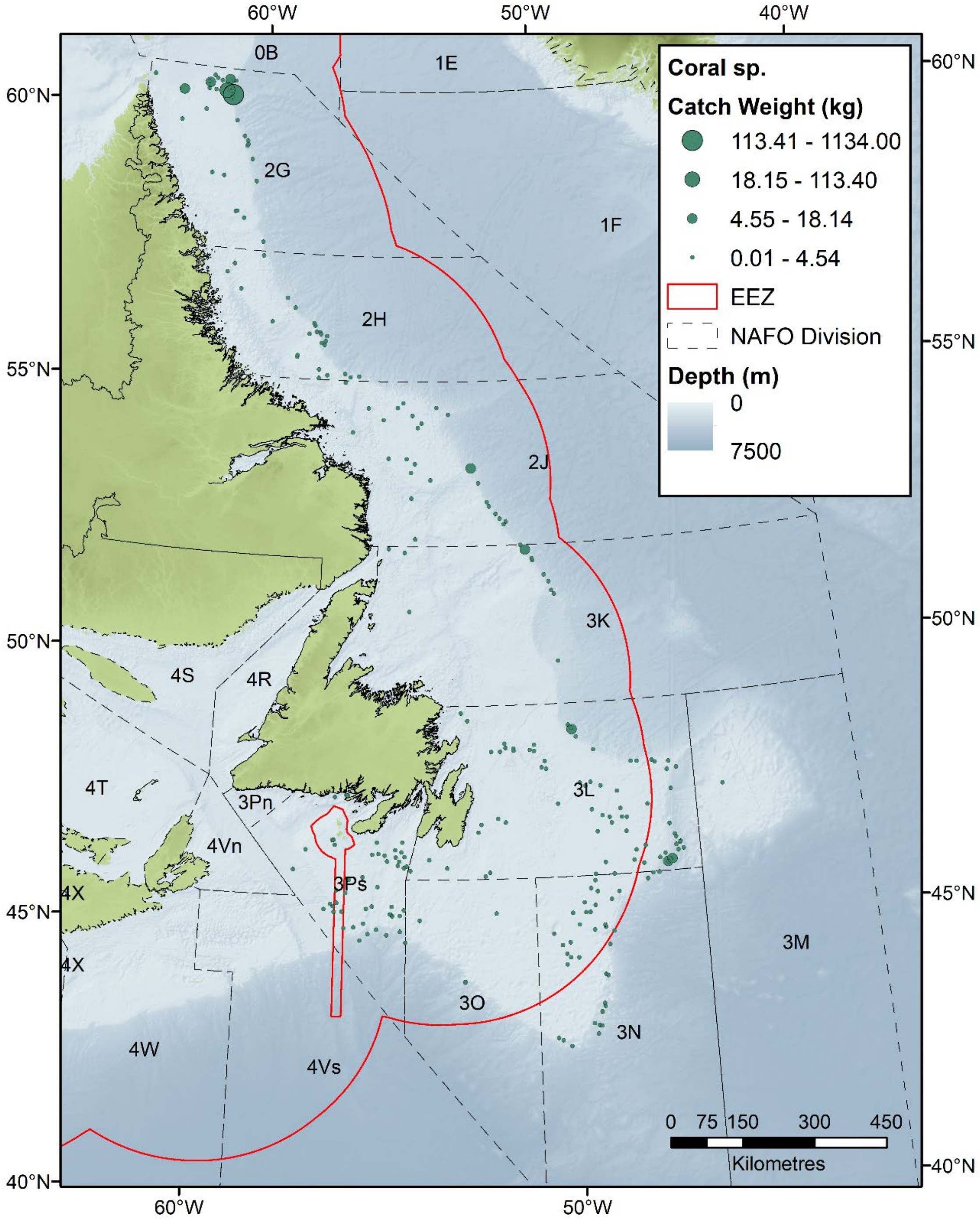


Figure 8: Distribution and catch weights of coral sp. (those not identified at the species or group level) in the NL region.

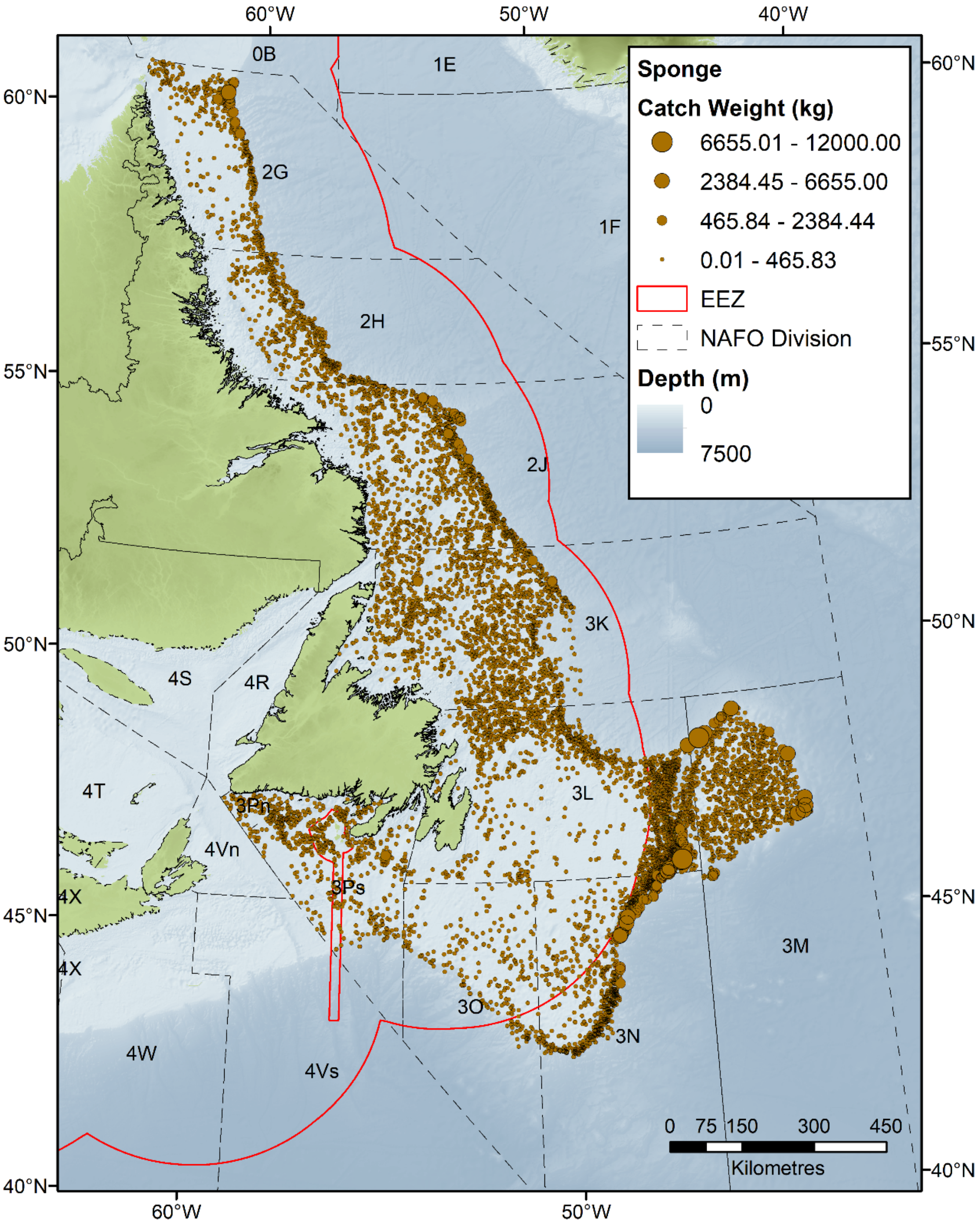


Figure 9: Distribution and catch weights of sponges in the NL region.

2.3. DENSITY

Although DFO RV trawl surveys represent the largest source of information for corals and sponges in the NL region, the physical damage imposed on specimens during the trawling process makes it difficult to accurately determine species abundance. Nonetheless, some work has been conducted using alternative methods such as ROVs (e.g. Baker et al. 2012), which has provided information on the density of some species within the NL region. Table 1 provides a non-exhaustive list of community metrics that have been reported in the scientific literature to date, but it should be recognized that there is ongoing work in this area of research.

While coral and sponge species can be found in high concentrations (Baker et al. 2012, Knudby et al. 2013), many are often observed sporadically. In the temperate waters of the Northwest Atlantic, sponges can be found forming dense aggregations known as sponge grounds (Kenchington et al. 2013). In the NL region they have been documented occurring along the slopes of the Grand Banks, Flemish Pass, Flemish Cap (Murillo et al. 2012), and the Labrador Shelf (Knudby et al. 2013). In the Northwest Atlantic, the density of sponge grounds typically ranges from 5–25 sponges/m^2 (Maldonado et al. 2017), reaching concentrations of more than 3 mt/hectare in *Geodia* grounds (Murillo et al. 2016a). These sponge grounds, sometimes referred to as an ostur, can contain up to 50 different species, but are typically dominated by just a few (*Geodia barretti, G. phlegraei, G. macandrewii, Stryphnus fortis* (published as *S. ponderosus),* and *Stelletta normani* (Klitgaard and Tendal 2004). Evidence suggests that these *Geodia* communities have existed for 1,000s of years, in some cases dating back to the last glacial maximum (Murillo et al. 2016a).

Coral garden species are those which form fields, rather than reefs. Such gardens can be comprised of many different coral and other benthic species and represent areas of high biodiversity in the deep sea. In the NL region, sea pen fields have been documented in the Laurentian Channel, Haddock Channel, and the Desbarres Canyon, spanning areas >1 km (Gilkinson and Edinger 2009, Baker et al. 2012). Like sponge grounds, sea pen fields are typically dominated by a small number of species, but the specific density of sea pen fields in the Northwest Atlantic has not been well documented (DFO 2018). Based on *in situ* observations from imagery, the sea pen *Halipteris finmarchica* dominate fields on the Scotian Shelf, while *Pennatula aculeata* is more common in the Laurentian Channel, Haddock Channel, and Desbarres Canyon, and appears to be limited to southern areas of the NL region (Hayes unpublished data). *Pennatula grandis* is usually seen as a secondary species, and has not been found to dominate habitats throughout the NL region; however, it is known to be more dominant in the East Baffin Bay region (Eastern Canadian Arctic, Hayes unpublished data) as well as at the mouth of the Laurentian Channel and in the Gulf of St. Lawrence (DFO 2018, Murillo et al. 2018). *Anthoptilum* spp. are also common in the Laurentian Channel (B. Neves pers. comm.).

Fields of the bamboo coral *Acanella arbuscula* have been reported within the Flemish Pass, as well as along the slope of the southwest Grand Bank and the Northern Labrador Sea (Baker et al. 2012, DFO 2018, Hayes unpublished data). They are considered to represent unique habitats in mud-dominated environments (Baker et al. 2012). Somewhat more diverse are the bamboo coral and sponge thickets which have been observed in Baffin Bay, the Flemish Pass, on the northeast Flemish Cap, as well as in the Haddock and Halibut Channels just east of the Laurentian Channel (Wareham 2009, Baker et al. 2012, Neves et al. 2015, DFO 2018). These aggregations are known to be predominantly comprised of *Asconema* spp. (glass sponge) and *Keratoisis* sp. (*Keratoisis* cf. *flexibilus*) (Saucier 2016). In the Eastern Canadian Arctic, *Keratoisis* sp. aggregations have been associated with elevated levels of infaunal diversity (Pierrejean et al. 2020). Information collected during ROV (Remotely Operated Platform for Ocean Sciences [ROPOS]) surveys in 2010 suggests that bamboo coral thickets are depth-dependent, particularly on the NE Flemish Cap, and existing research indicates they are found in high concentrations between 1,200 and 1,300 m depth and can co-occur with high abundances of sponges (Murillo et al. 2011, Miles 2018). However, as depths decrease, communities transition to a mix of other sponges and *Geodia* (e.g. NE Flemish Cap [Miles 2018]). In contrast, at depths >1,300 m communities are largely dominated by *Geodia* (Beazley et al. 2013a, Murillo et al. 2016a, Miles 2018, DFO 2018).

Table 1: Reported metrics of habitat forming coral and sponge communities based on their most dominant species.

Community Type	**Genus and/or Species**	**Reported Community Scale Metrics**
Sea Pen Fields	*Pennatula aculeata* *Pennatula grandis* *Anthoptilum grandiflorum* *Halipteris finmarchica*	**Patch Size:** Fields can reach several kilometres (Baker et al. 2012); 10's of kilometres (Murillo et al. 2018) **Density/Abundance:** 622 colonies of *Pennatula* spp. in a 10 m segment (Baker et al. 2012); 100 kg of sea pens in a 1 km trawl set (Kenchington et al. 2016a, 2016b); 0–8 colonies/m^2 of *P. aculeata* in Gulf of Maine (Langton et al. 1990); 4.7 colonies/m^2 of *H. finmarchica* in trawled areas of West Greenland (Long et al. 2018)
Acanella Meadows	*Acanella arbuscula*	**Patch Size:** "Large coral fields" on SW Grand Banks (Baker et al. 2012), and described as occurring nearly continuously on the southern Flemish Cap slope (NAFO 2013); patches <500 m (Beazley 2008) **Density/Abundance:** 77 colonies in a 10 m video transect (Baker et al. 2012); 0.5 colonies/m^2 in West Greenland (Long et al. 2018)
Geodia Sponge Grounds (Ostur)	*Geodia*	**Patch Size**: "Sponge grounds on the Canadian side are very extensive and seemingly dominated by *Geodia*..." (Hogg et al. 2010, Fuller 2011) **Density/Abundance:** 5–25 sponges/m^2 (Maldonado et al. 2017)
	Stryphnus	**Density/Abundance:** 5–25 sponges/m^2 (Maldonado et al. 2017)
	Stelletta	**Density/Abundance:** 5–25 sponges/m^2 (Maldonado et al. 2017)
Bamboo and Sponge Thickets	*Asconema* spp.	**Density/Abundance:** 5–25 sponges/m^2 (Maldonado et al. 2017)
	Keratoisis grayi	**Density/Abundance:** 43 colonies in a 10 m transect (Baker et al. 2012)
	Keratoisis sp.	**Patch Size:** 55 m (Neves et al. 2015) **Density/Abundance:** "Colonies are considered dense because their appearance was very crowded, such that individual colonies could not be distinguished." (Neves et al. 2015)
Soft corals	*Nephtheidae* spp.	**Density/Abundance:** >500 colonies per 100 m^2 (Mortensen et al. 2006)
	Clavularia spp.	**Density/Abundance:** 1.7 colonies per m^2 (Stone 2006)

Community Type	Genus and/or Species	Reported Community Scale Metrics
	(Aleutian Islands, Alaska)	
Large gorgonians	*Paragorgia arborea*	**Patch Size:** 10–100 m (Mortensen and Buhl-Mortensen 2004) **Density/Abundance:** 49 colonies per 100 m^2
Gorgonians	Gorgonian spp. (Aleutian Islands, Alaska)	**Density/Abundance:** 2.32 colonies per m^2 (Stone 2006)
Sea Pens	*Protoptilum* sp. (Aleutian Islands, Alaska)	**Density/Abundance:** 16 colonies per m^2 (Stone 2005)
Black Corals	Antipatharians	**Density/Abundance:** 1 colony per m^2 (Stone and Shotwell 2007)
	Leiopathes sp. (NE Atlantic)	**Density/Abundance:**Colonies <30 cm; 9.436 ind. per m^2 Colonies between 30–100 cm; 0.125 ind. per m^2 Colonies >100 cm; 0.364 ind. per m^2 (De Clippele et al. 2019)
Hydrocorals	Stylasteridae spp. (Aleutian Islands, Alaska)	**Density/Abundance:** 3.65 colonies per m^2 (Stone 2006)

2.4. HABITAT REQUIREMENTS

Although some variables associated with the distribution of coral and sponge species may be related (e.g. slope and substrate type) (Bryan and Metaxas 2007, Edinger et al. 2011), habitat suitability typically varies as a function of depth, temperature, salinity, slope, surface productivity, current strength, and substrate type and local topography (Roberts et al. 2009). Due to the amount of fishing that has occurred off the coast of NL, there is uncertainty surrounding the influence of bottom-contact fisheries on the observed depth ranges for corals and sponges (Murillo et al. 2016a). Existing data suggest that coral species exist at depths of <100 m to over 2,000 m, although most observations have been limited by minimum and maximum RV trawl survey depth (Kenchington et al. 2009, Edinger et al. 2011, Baker et al. 2012), with the highest concentrations reported in the NRA (the Flemish Cap, Flemish Pass, and portions of the Grand Banks) from depths of 600 to 1,470 m (Murillo et al. 2011, Hayes unpublished data). ROV imagery from the Grand Banks, Flemish Cap, and Orphan Knoll has revealed the presence of corals at depths >2,000 m and up to 2,900 m (Baker et al. 2012, Miles 2018, Meredyk et al. 2020). Globally, marine sponges have been observed at depths up to 8,000 m (Hogg et al. 2010), with species found in waters as shallow as 105 m in the NL region (Kenchington et al. 2010), and in even shallower coastal areas (B. Neves pers. comm.). In the NRA, catches range between 950 to 1,470 m (Murillo et al. 2012), but have been observed at depths as shallow as 138 m (Murillo pers. comm.).

Throughout their geographic extent, different coral and sponge species also associate with different substrate types. In general, soft corals exist attached to gravel or shell fragments on sand/mud substrate, cup corals are either free lying on mud/sand or attached to bedrock or cobble, and small gorgonians and sea pens are most typically associated with soft substrates. In contrast, the distribution of large gorgonians and black corals depends largely on the presence of hard substrates (Edinger et al. 2011), although certain large gorgonians (e.g. *Keratoisis* spp.) can also be found growing directly on soft substrates (Neves et al. 2015). Like corals, most sponges show a preference for hard substrates; however, some have developed morphological adaptations that allow them to occupy areas with soft substrates and elevated levels of sedimentation (Hogg et al. 2010).

Recent modelling work has also shown that the heightened levels of productivity associated with surface chlorophyll-a concentrations are also good predictors of habitat suitability for both corals and sponge species (Edinger et al. 2011, Knudby et al. 2013, Beazley et al. 2016, Guijarro et al. 2016, Gullage et al. 2017). Furthermore, because most cold-water coral and sponge species are sessile, they also rely on the presence of currents to maintain the suspension of particulate matter within the water column and prevent the buildup of fine sediments which could smother them (Roberts et al. 2006, Bryan and Metaxas 2007, Edinger et al. 2007, Hogg et al. 2010). In areas where currents are relatively strong, the consistent suspension and redistribution of fine sediments leads to the exposure of hard substrates (Edinger et al. 2011). As a result, species that anchor on hard substrates (e.g. large gorgonians, black corals) are thought to be most dependent upon currents (Bryan and Metaxas 2007, Edinger et al. 2011). In contrast, species in environments dominated by soft substrates are more likely to withstand periods of low currents and subsequent sedimentation (Edinger et al. 2011).

2.4.1. Oceanographic Context

The physical environment of the NL shelves is unique in that it hosts the interaction of subpolar and subtropical waters (Figure 10). A key feature of the ocean circulation characterizing the region is the southward flowing Labrador Current system. This current is usually separated into two distinct inshore and offshore branches. The inshore branch originates near the northern tip of Labrador where outflow through the Hudson Strait combines with the East Baffin Island Current and flows southward along the Labrador coast filling the shelf with cold and fresh water. The offshore and main branch of the Labrador Current consists of warmer and saltier subpolar waters and flows along the shelf break, forming the western boundary of the Labrador Sea. This current is part of the large-scale North Atlantic circulation by forming the western portion of the Subpolar Gyre. South of 50°N, the shallower inner branch becomes broader and less defined as it circulates counterclockwise around the island of Newfoundland through the Avalon Channel, the main branch of the Labrador Current reaches the Flemish Pass and Flemish Cap area. While an important fraction of the Labrador Current flows directly through Flemish Pass to reach the tail of the Grand Bank, another fraction is deviated eastward and circulates clockwise around the Flemish Cap.

The region of the Flemish Pass/Cap and the tail of the Grand Bank is also where the Labrador Current meets another key oceanographic feature, the North Atlantic Current (NAC), the offshore extension of the Gulf Stream. The NAC carries warmer, high salinity, subtropical water northeastward to the middle of the North Atlantic and forms the southern portion of the Subpolar Gyre. A portion of NAC waters also enters the eastern Flemish Pass area, further contributing to a topographically induced anticyclonic gyre over the central portion of the Flemish Cap.

The strength of the currents described above, and thus the strength of the North Atlantic Subpolar Gyre, varies on seasonal, interannual and decadal time scales (e.g. Buckley and Marshall 2016). These changes can significantly affect physical and biological environments, the composition of water masses, and the ability of the currents to potentially disperse material in the region. These currents are also sensitive to climate change (e.g. Seidov et al. 2017).

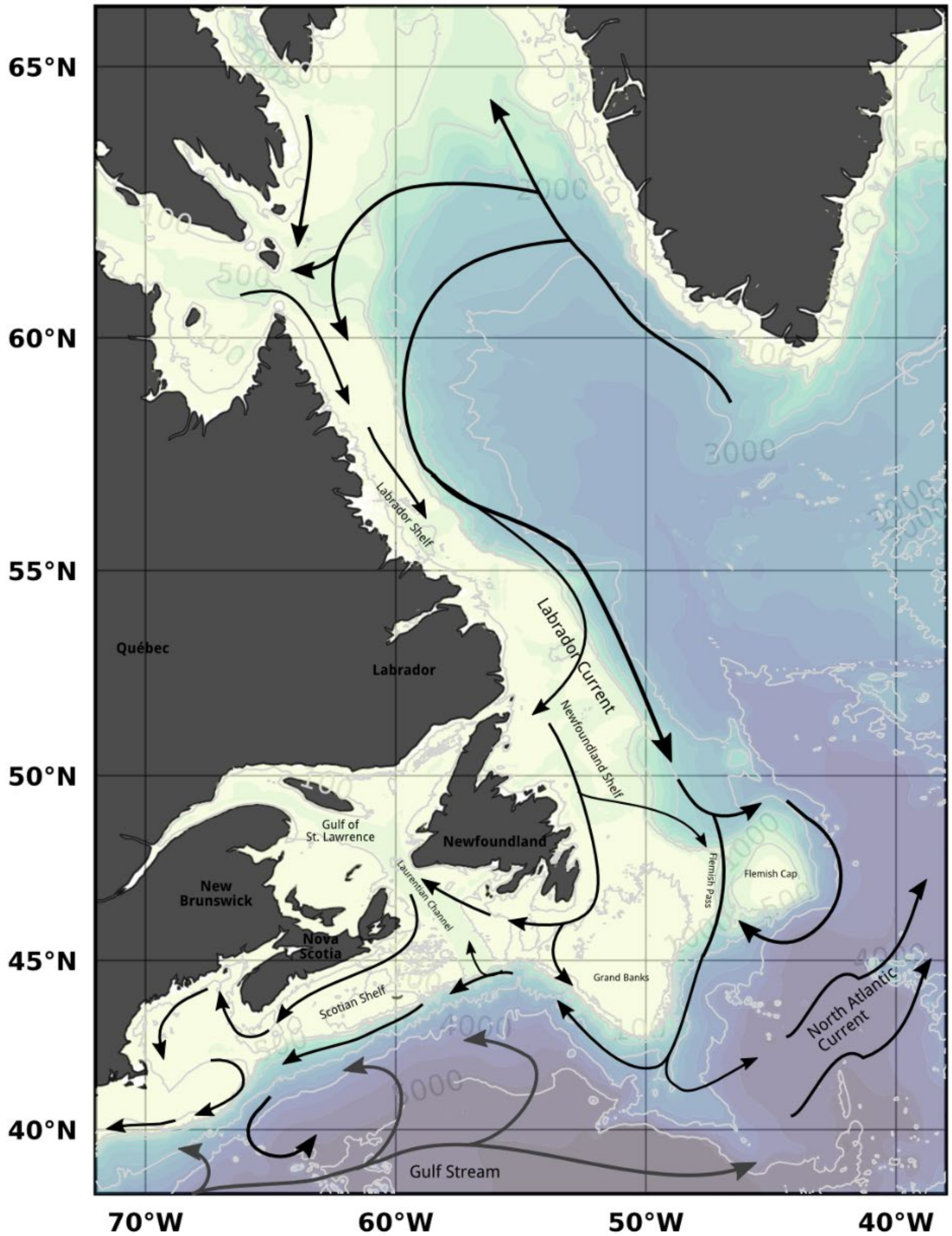


Figure 10: General oceanographic currents present in the NL region. Modified from Cyr et al. (2020). Black arrows are representative of subpolar waters and dark gray arrows are representative of subtropical waters (e.g. the Gulf Stream).

2.5. SENSITIVITIES

Because of their slow growth, longevity, and sessile nature, coral and sponge species can be particularly vulnerable to disturbances (Wareham and Edinger 2007, Heifetz et al. 2009, Roberts et al. 2009). However, their sensitivity depends largely on the nature of the disturbance and the species being impacted. Bottom contact fishing, subsea infrastructure installation, dredging, mining, aquaculture, and offshore oil and gas exploration all have the potential to impact corals and sponges (Roberts et al. 2006, Wilding 2011, Ragnarsson et al. 2016, Schönberg 2016). Not only do these activities increase the risk of physical damage to the species, but they also expose them to increased sedimentation/turbidity, and in some cases harmful chemicals (Ragnarsson et al. 2016).

Due to their somewhat rigid skeletons and long-lived nature, large gorgonians and black corals are most at risk of physical damage and mortality. In contrast, smaller and more flexible colonies with faster growth rates and shorter lifespans, such as some species of soft corals, sea pens, and sponges, likely have a lower risk of damage and mortality (Austin et al. 2007, Edinger et al. 2007). However, even the more resilient species can experience long-term declines in survival and health after physical damage. Malecha and Stone (2009) found that although some colonies of the sea pen *Halipteris willemoesi* were able to rebury and upright themselves after induced dislodgment, they were at an increased risk for future dislodgements even without exposure to additional disturbances, and dislodged colonies also experienced higher levels of predation.

Because most cold-water coral and sponge species obtain nutrients and food directly from the water column, many are also sensitive to increased rates of sedimentation (Ragnarsson et al. 2016, Schönberg 2016), and exposure to waterborne chemicals originating from anthropogenic activities (White et al. 2012, Edge et al. 2016, Ragnarsson et al. 2016, Fang et al. 2018). Depending on the amount and duration of the heightened sedimentation, impacts range from reductions in feeding and respiration rates (Tjensvoll et al. 2013, Bell et al. 2015a, 2015b, Grant et al. 2018) to smothering and mortality (Freiwald and Roberts 2005, Wulff 2008, Bell et al. 2015a, 2015b). Impacts of exposure to chemicals have been associated with changes in behaviour, fitness, and survival (Edge et al. 2016, Ragnarsson et al. 2016, Fang et al. 2018), and gorgonian corals have been documented exhibiting excess mucus production, retracted polyps, tissue loss, sclerite enlargement, and increased rates of colonization by parasitic hydroids after exposure to flocculent material (White et al. 2012, Hsing et al. 2013). In general, sponge species that are thought to be more resilient to sedimentation are those that have lower ratios of horizontal tissue area, those whose pores are located on elevated body parts, or those that can keep their surface sediment free with limited effort (Schönberg 2016). Nonetheless, sponges can be at a heightened risk during their larval phase (Schönberg 2016) because elevated levels of sedimentation reduce the amount of habitat suitable for settlement (Hogg et al. 2010), and the post-settlement stage can involve flattening and spreading which increases surface area and the likelihood of smothering (Leys and Degnan 2002, Maldonado 2008). Sedimentation of drill cuttings has also been found to clog the cilia of coral larvae, which impacts swimming and feeding activities, and has been linked with elevated levels of mortality (Järnegren 2017). Currently very little is known about the reproductive patterns of cold-water sponge species, but they are thought to be seasonal and infrequent (Klitgaard and Tendal 2004), suggesting exceptional vulnerability to anthropogenic activities during these periods (Hogg et al. 2010).

2.6. EXISTING SPECIAL AREAS

Several special areas have been identified in the NL Region based on significant concentrations of corals and sponges (Table 2). A portion of these areas have also been protected using various forms of legislation, including the *Fisheries Act* and the *Oceans Act.* Protection standards have been developed by the Government of Canada for MPAs and OECMs (including Marine Refuges [MRs]), in order to conserve sensitive and important parts of the ocean. For all federal MPAs, four key industrial activities are prohibited: oil and gas activities, mining, dumping, and bottom trawling. For OECMs, activities proposed within these areas will be assessed on a case-by-case basis. Some activities may be allowed if they are consistent with the conservation objectives of a specific area but before any proposed activity can take place, the Minister of Fisheries, Oceans and the Canadian Coast Guard will need to be satisfied that any risks to the area have been avoided or mitigated effectively. Once oil and gas extraction begins within an OECM, the portion of the oil and gas license or permit that overlaps with the OECM will no longer count towards Canada’s marine conservation targets.

The term “special areas”, in the context of this document, is used to refer to special areas for corals and sponges, and includes SiBAs, VME habitats and closures, EBSAs, OECMs (including MRs), and MPAs. In 2009, the Food and Agriculture Organization (FAO) defined concentrations of coral and/or sponge species as VMEs (FAO 2009), leading to the eventual delineation of 30 VME habitats (9 large gorgonian VMEs, 14 sponge VMEs, and 7 sea pen VMEs; NAFO 2013, 2017; Figure 11) and the subsequent closure of 20 areas to bottom-contact fishing gear in the NRA (Figure 12; NAFO 2019a). SiBAs are similar to VMEs in their definition but are located within domestic waters. Additional work by DFO Science has led to the identification of SiBAs (Figure 11). While the identification and delineation of VMEs and SiBAs do not automatically result in their protection, fisheries closures have been established in the NRA to protect portions of some VME habitats, and OECMs have been established within the EEZ to protect portions of some SiBAs.

RV trawl survey catch weights (kg) have been used to identify areas that contain particularly high concentrations of coral and sponge species (e.g. SiBAs and VME habitats). Various approaches have been taken including kernel density analysis (KDE), species distribution models (SDMs), and expert knowledge (Kenchington 2014, 2016ab, 2019a, Guijarro et al. 2016). Some VME habitat areas have been extended based on imagery data (e.g. NE Flemish Cap; NAFO 2019b). In 2019a, Kenchington et al. performed KDE analyses on data beyond the Canadian EEZ to support the generation of updated VME habitats for large gorgonians, small gorgonians, sea pens, and sponges in the NRA, as well as new VME habitats for black corals (Figure 13). Because soft corals and cup corals are not considered VME indicator species in the Northwest Atlantic, areas containing significant concentrations of these corals have not been defined at this time. While new VME habitats have recently been proposed for black corals beyond the EEZ (Kenchington et al. 2019a), limited observations of black corals within the EEZ have prevented the delineation of SiBAs in domestic waters.

Five MRs have been established by DFO as OECMs which have conservation objectives related to the protection of corals and sponges within the NL bioregion (Figure 14; DFO 2019b). Three of these areas (Northeast Newfoundland Slope, Hopedale Saddle, and Hatton Basin) were based on SiBAs but the protected areas only represent a portion of the delineated SiBA.

In separate processes, EBSAs have also been identified throughout the NL region, some of which were based on significant concentrations of coral and sponge species (Figure 15; DFO 2013, 2019b, 2019c, Wells et al. 2017). The Laurentian Channel was originally identified as an EBSA (Templeman 2007) and was officially designated as an *Oceans Act* MPA in 2019, with one of the conservation objectives being the protection of corals, particularly significant concentrations of sea pens, from harm due to human activities. While no additional Areas of Interest (AOIs) have been formally announced in the NL bioregion to date, EBSAs are a priority for protection as part of MPA network planning.

Because of the heightened concentrations of corals and sponges in the special areas described above, the severity of impacts resulting from anthropogenic activities are likely to be elevated there (DFO 2019d). As a result, it is recommended that exploratory drilling activities occurring within their boundaries should automatically be subject to avoidance and special mitigation measures, regardless of whether the areas are protected from other human activities or not.

Table 2: List of existing SiBAs, VMEs, EBSAs, and closed areas (MPAs, MRs, and VME closures) in the NL region where corals and/or sponges are identified as Conservation Objectives, Key Features, or Other Features. Except for the Laurentian Channel MPA (Figure 16), there are no locations in the NL offshore area where exploratory drilling is currently prohibited. Therefore, several special areas listed in Table 2 have the potential to be impacted by exploratory drilling.

Corresponding Map ID	**Name**	**Type**	**Designated by**	**Conservation Objective(s) and/or Key Features (for EBSAs)**
-	Laurentian Channel	MPA	DFO	Protect corals (particularly Sea Pens), Black Dogfish, Smooth Skate, Porbeagle Sharks, Northern Wolffish
1	Hatton Basin Closure	MR	DFO	To conserve sensitive benthic areas (e.g. large gorgonians and *Geodia* sponges)
2	Hopedale Saddle Closure	MR	DFO	Protect corals and sponges and contribute to the long-term conservation of biodiversity
3	Northeast Newfoundland Slope Closure 1	MR	DFO	Protect corals and sponges and contribute to the long-term conservation of biodiversity
4	Northeast Newfoundland Slope Closure 2	MR	DFO	Protect corals and sponges and contribute to the long-term conservation of biodiversity
5	3O Coral Closure	MR	DFO	Protect coral and sponges (e.g. coral biodiversity)
1	Orphan Knoll	VME Closure	NAFO	Protect coral and sponges, including cup coral
2	Sackville Spur	VME Closure	NAFO	Protect sponge grounds (e.g. *Geodia* communities)
3	Northern Flemish Cap	VME Closure	NAFO	Protect sea pen fields
4	Northern Flemish Cap	VME Closure	NAFO	Protect sea pen fields, crinoids, cerianthids, and black corals
5	Northern Flemish Cap	VME Closure	NAFO	Protect sea pen fields, crinoids, cerianthids, and black corals
6	Northeast Flemish Cap	VME Closure	NAFO	Protect corals and sponges (e.g. large gorgonians and sponges)
7	Eastern Flemish Cap	VME Closure	NAFO	Protect large gorgonians and sponge grounds
8	Northwest Flemish Cap	VME Closure	NAFO	Protect sea pen fields, crinoids, cerianthids, and black corals

Corresponding Map ID	Name	Type	Designated by	Conservation Objective(s) and/or Key Features (for EBSAs)
9	Northwest Flemish Cap	VME Closure	NAFO	Protect sea pen fields, crinoids, cerianthids, and black corals
10	Northwest Flemish Cap	VME Closure	NAFO	Protect sea pen fields, crinoids, cerianthids, and black corals
11	Flemish Pass / Eastern Canyon	VME Closure	NAFO	Protect sponge grounds and large gorgonians
12	Beothuk Knoll	VME Closure	NAFO	Protect large gorgonians and sponges
13	Beothuk Knoll	VME Closure	NAFO	Protect sponge grounds
14	Tail of the Bank	VME Closure	NAFO	Protect sponge grounds, small gorgonians
15	3O Coral Closure	VME Closure	NAFO	Protect coral and sponges (e.g. coral biodiversity)
-	Large Gorgonians SiBA	SiBA	DFO	Protect large gorgonians
-	Small Gorgonians SiBA	SiBA	DFO	Protect small gorgonians
-	Sea Pen SiBA	SiBA	DFO	Protect sea pens
-	Sponge SiBA	SiBA	DFO	Protect sponges
-	Large Gorgonian VME	VME Habitat	NAFO	Protect large gorgonians
-	Small Gorgonian VME	VME Habitat	NAFO	Protect small gorgonians
-	Sea Pen VME	VME Habitat	NAFO	Protect sea pens
-	Sponge VME	VME Habitat	NAFO	Protect sponges
1	Outer Shelf Saglek Bank	EBSA	DFO	Sea Pens, Large Gorgonians, Sponges, Harp Seals, Hooded Seals, Cetaceans, Seabirds, Ivory Gull
2	Outer Shelf Nain Bank	EBSA	DFO	Sea Pens, Black Corals, Soft Corals, Cup Corals, Small Benthivores, Medium Benthivores, Planktivores, Hooded Seals, Seabirds, Ivory Gull
3	Hopedale Saddle*	EBSA	DFO	Belugas *
4	Labrador Slope	EBSA	DFO	Sponges, Soft Corals, Black Corals, Atlantic Wolffish, Spotted Wolffish, Northern Wolffish, Roundnose Grenadier, Skates, Shrimp, Greenland Halibut, Redfish, Atlantic Cod, American Plaice, Small Benthivores, Medium Benthivores, Large Benthivores, Plantivores, Plankpiscivores, Piscivores

Corresponding Map ID	Name	Type	Designated by	Conservation Objective(s) and/or Key Features (for EBSAs)
5	Gilbert Bay*	EBSA	DFO	Genetically distinct resident population of Atlantic Cod*
6	Grey Islands*	EBSA	DFO	Harlequin Duck, Sea ducks, Waterfowl, Seabirds, Seabird colonies*
7	Orphan Spur	EBSA	DFO	Corals diversity, Soft Corals, Sea Pens, Black Corals, Cup Corals, Small Gorgonians, Roundnose Grenadier, Skates, Northern Wolffish, Spotted Wolffish, Atlantic Wolffish, American Plaice, Redfish, Atlantic Cod, Witch Flounder, Small Benthivores, Medium Benthivores, Large Benthivores, Piscivores
8	Northeast Slope	EBSA	DFO	Large Gorgonian Corals, Sea Pens, Black Corals, Soft Corals, Sponges, Shrimp, Greenland Halibut, Northern Wolffish, Spotted Wolffish, Roughhead Grenadier, Black Corals, Capelin, Witch Flounder, American Plaice, Atlantic Cod, Atlantic Wolffish, Thorny Skate, Smooth Skate, Piscivores, Planktivores, Plank-Piscivores, Small Benthivores, Medium Benthivores, Large Benthivores, Common Murre, Thick-billed Murre, Hooded Seal,
9	South Coast	EBSA	DFO	Sea Pens, Sponges, Common Eider colonies, Eelgrass habitat, Shrimp, Atlantic Cod, Redfish, Piscivores, Planktivores, Plank-Piscivores, Black Dogfish, Smooth Skate, Surface shallow-diving coastal piscivores, Surface shallow-diving piscivores, Blue Whale, Hooded Seal, Grey Seal
10	Placentia Bay	EBSA	DFO	Large Gorgonian Corals, Sponges, Leatherback Turtle, Eelgrass habitat, Salmon, Hooded Seal, Mysticetes, Leatherback Turtle, Blue Whale, Plunge-diving piscivores, Shearwater sp., Icthyoplankton, Marine Mammals, Capelin spawning, Common Murre, Razorbill, Black-legged Kittiwake, Northern Gannet, Tern sp., Salmon, Blue Whale

Corresponding Map ID	Name	Type	Designated by	Conservation Objective(s) and/or Key Features (for EBSAs)
11	St. Mary's Bay*	EBSA	DFO	Common Murre colonies, Northern Gannet colonies, Harlequin Duck, Eelgrass habitat, Salmon, Common Eider, Harlequin Duck, Capelin, Mysticetes, Hooded Seal, Plunge-diving piscivores, Capelin spawning, Razorbill colonies, Black-legged Kittiwake colonies, Salmon, Leatherback Turtle
12	Eastern Avalon*	EBSA	DFO	Atlantic Puffin colonies, Common Murre colonies, Thick-billed Murre colonies, Northern Fulmar colonies, Razorbill colonies, Black-legged Kittiwake, Eelgrass habitat, Capelin, American Plaice, Killer Whale, Mysticetes functional group, Plunge-diving Piscivores, Pursuit-diving piscivores, Surface shallow-diving piscivores, American Plaice, Killer Whale
13	Laurentian Channel	EBSA	DFO	Sea Pens, Small Gorgonian Corals, Greenland Halibut, Winter Skate, Witch Flounder, Smooth Skate, Spotted Wolffish, Thorny Skate, White Hake, Winter Skate, Black Dogfish, Spiny Dogfish, Small benthivores, Medium benthivores, Large benthivores, Planktivores, Plankpiscivores, Piscivores, Blue Whale
14	Haddock Channel Sponges	EBSA	DFO	Largest sponge SBA on the shelf in the study area, Sponges, Capelin, American Plaice
15	Southwest Slope	EBSA	DFO	Small Gorgonian Corals, Black Corals, Large Gorgonian Corals, Cup Corals, Sea Pens, Roundnose Grenadier, Haddock feeding and spawning, Redfish spawning, Witch Flounder, Atlantic Halibut, American Plaice, Atlantic Cod, Northern Wolffish, Redfish, Smooth Skate, Thorny Skate, White Hake, Winter Skate, Small benthivores, Large benthivores, Planktivores, Plankpiscivores, Piscivores, Surface shallow-diving piscivores, Blue Whale, American Plaice spawning

Corresponding Map ID	Name	Type	Designated by	Conservation Objective(s) and/or Key Features (for EBSAs)
16	Lilly Canyon-Carson Canyon	EBSA	DFO	Soft Corals, Sponges, Roughhead Grenadier, Snow Crab, Greenland Halibut, American Plaice, Redfish, Thorny Skate, Small benthivores, Common Murre, Sooty Shearwater, Shallow pursuit generalists, Surface shallow-diving piscivores, Blue Whale, Harp Seals (winter feeding)

* While corals or sponges were not key features leading to the identification and delineation of these EBSAs, corals or sponges were found in these EBSAs and were included in a list of “Other Features” for each EBSA.

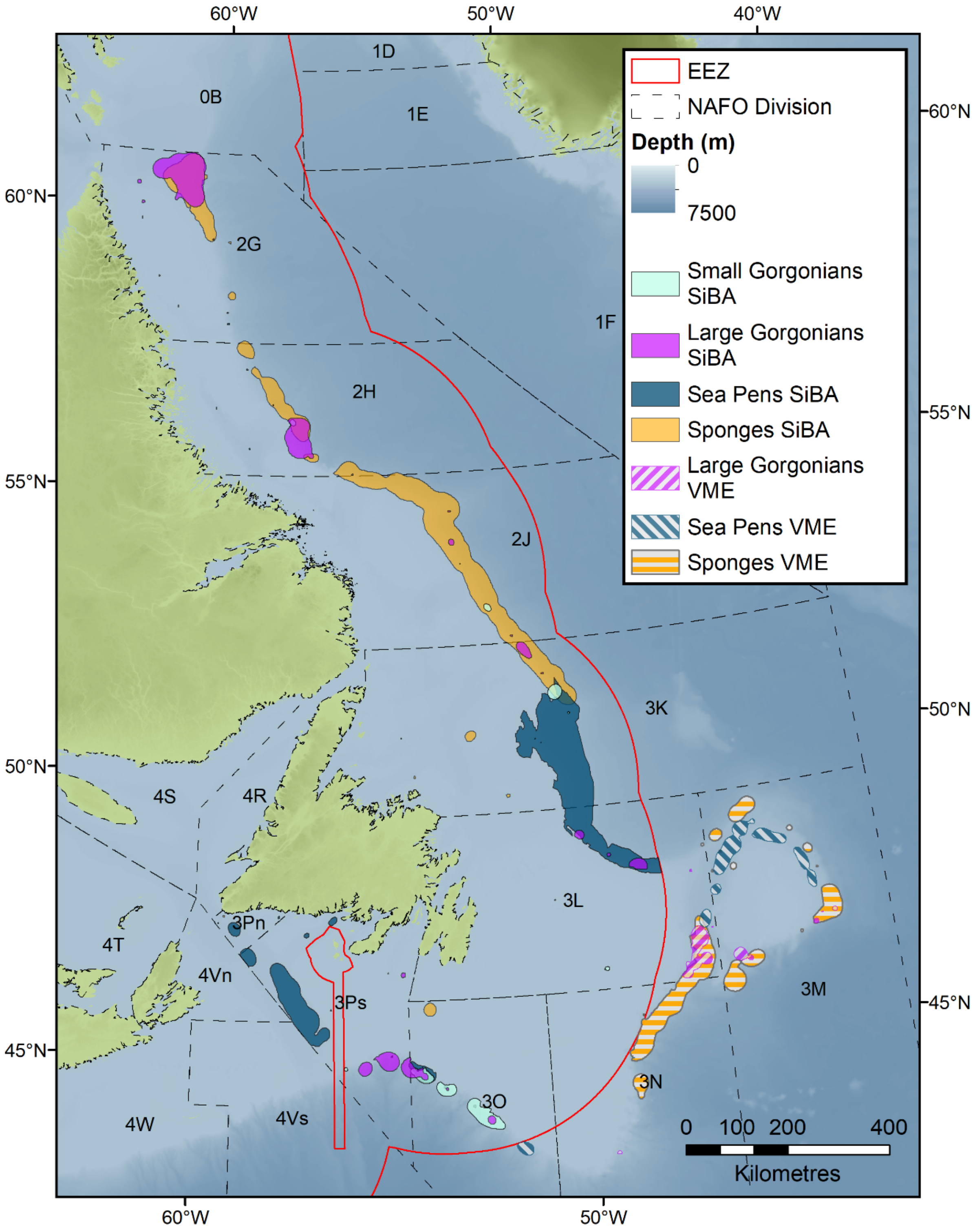


Figure 11: Location of SiBAs and VME habitats currently defined in the NL region (description of individual SiBAs and VME habitats available in Table 2).

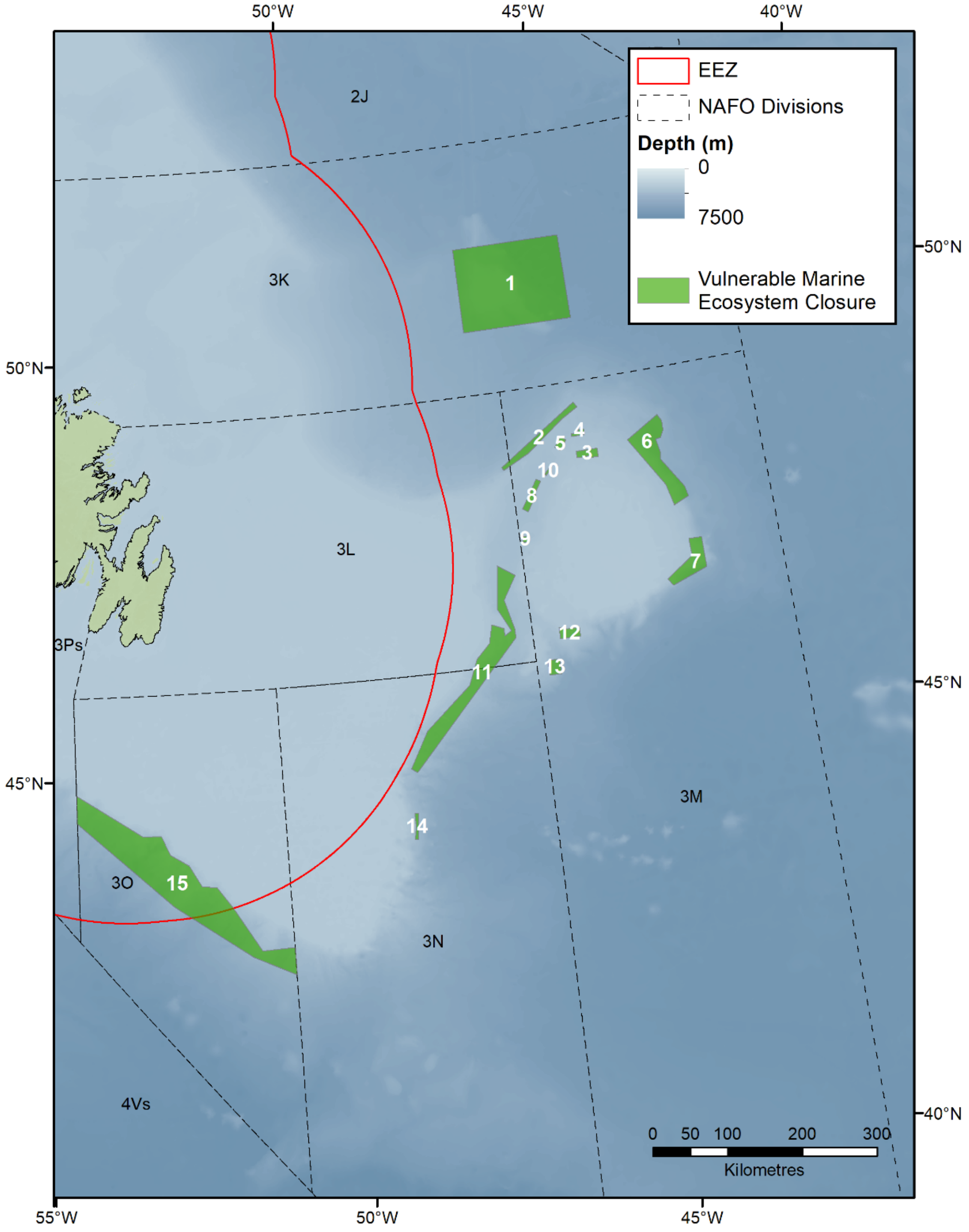


Figure 12: Location of VME Closures identified in the NRA where corals and/or sponges are identified as Key Features (description of individual VME closures available in Table 2).

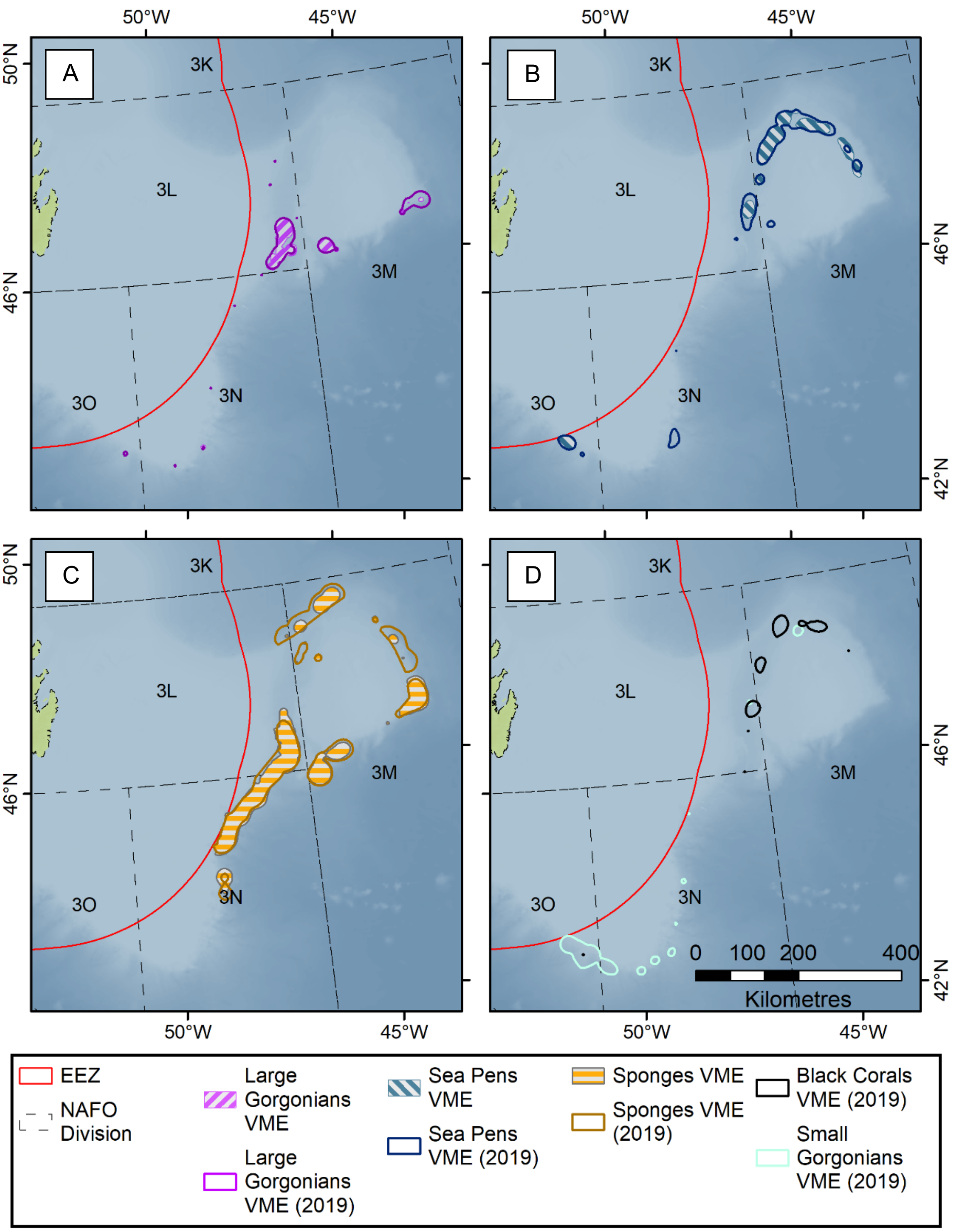


Figure 13: Comparison between existing and proposed VME habitats for large gorgonians (A), sea pens (B), sponges (C), black corals (D), and small gorgonians (D) (Adapted from Kenchington et al. 2019a). Boundaries for small gorgonian and black coral VME habitats have not been delineated in the past.

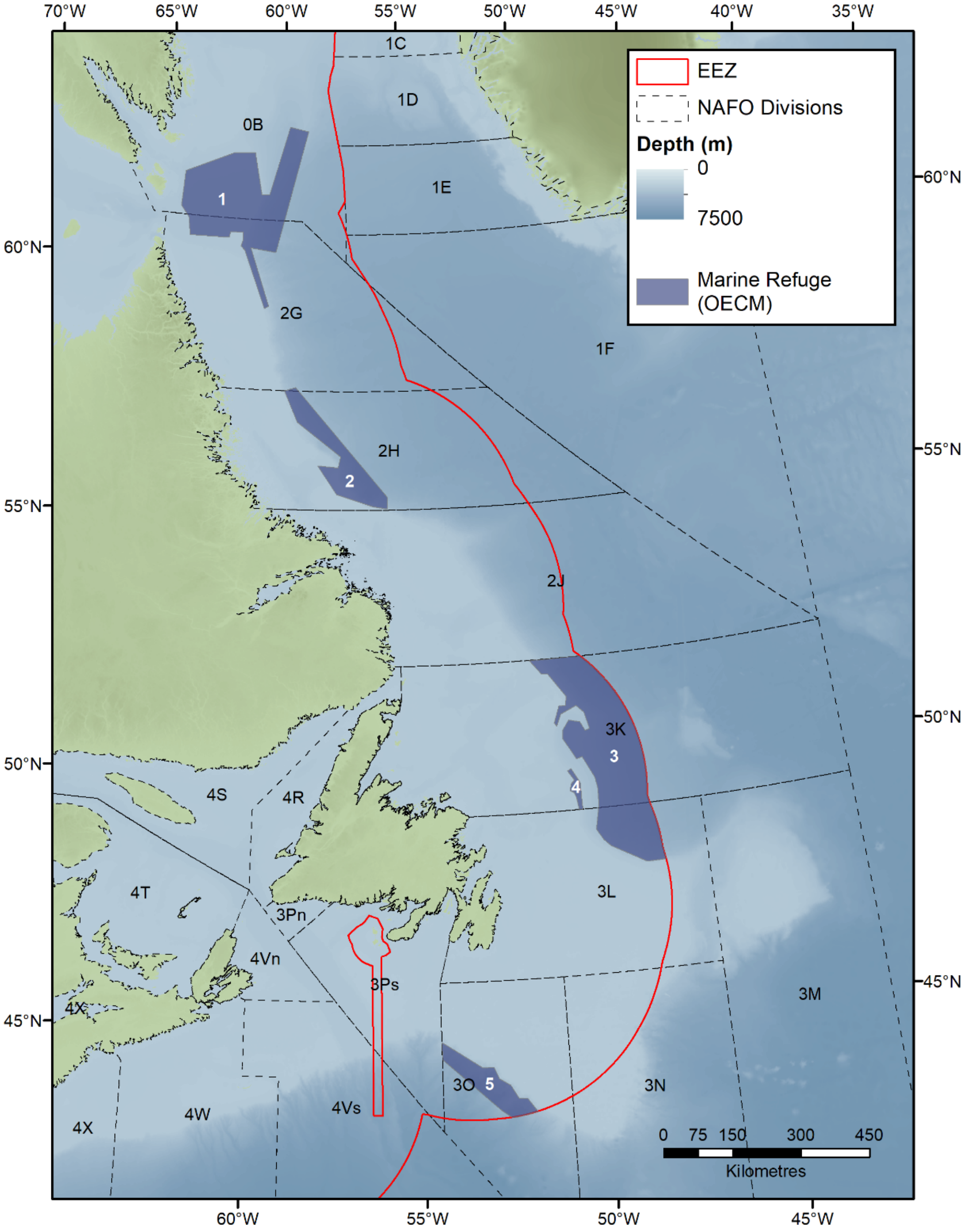


Figure 14: Location of Marine Refuges (MRs) identified in the NL region where coral and/or sponges are identified as Conservation Objectives (description of individual MRs available in Table 2).

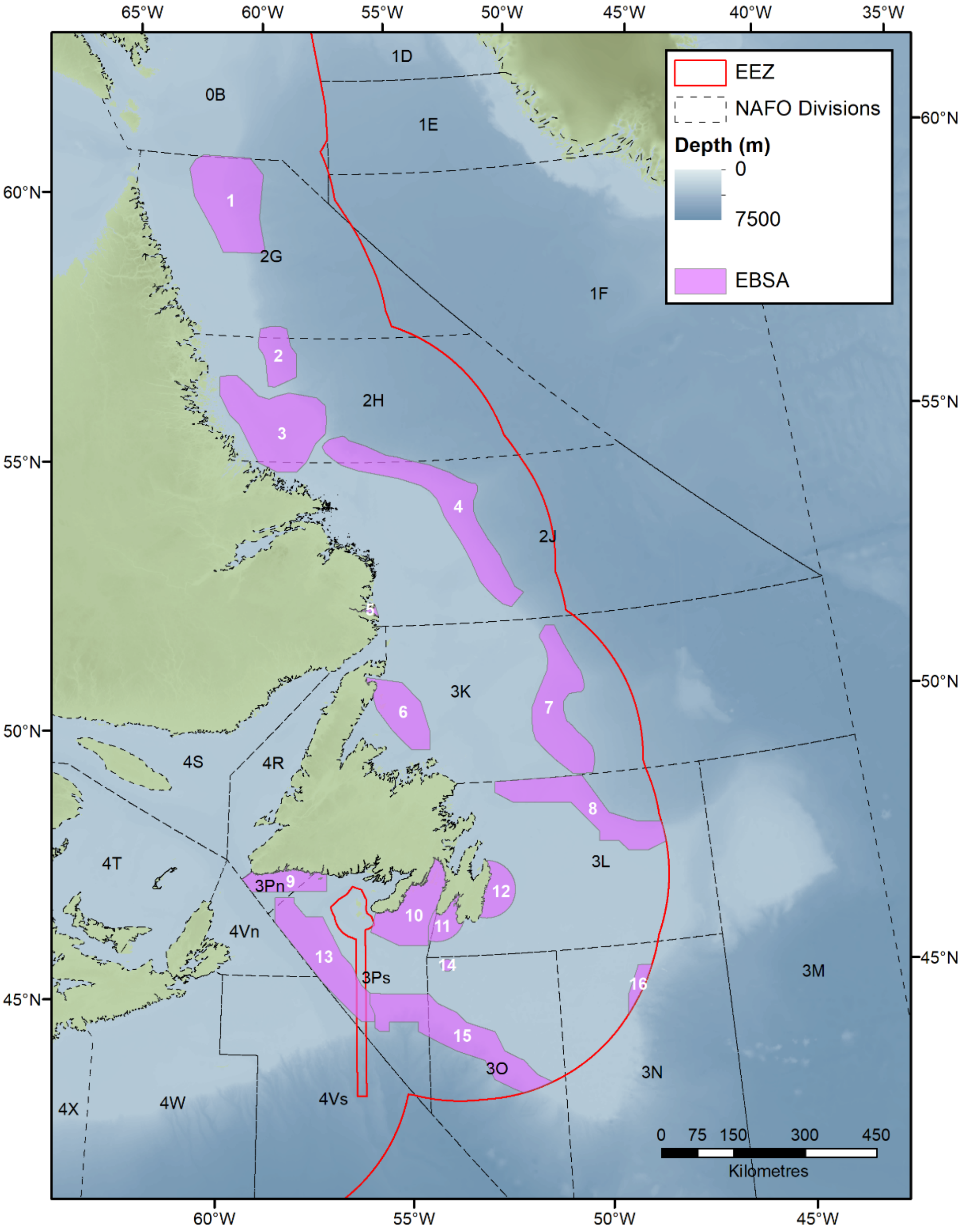


Figure 15: Location of Ecologically and Biologically Significant Areas (EBSAs) identified in the NL region where corals and/or sponges are identified as Conservation Objectives or Other Features (description of individual EBSAs available in Table 2).

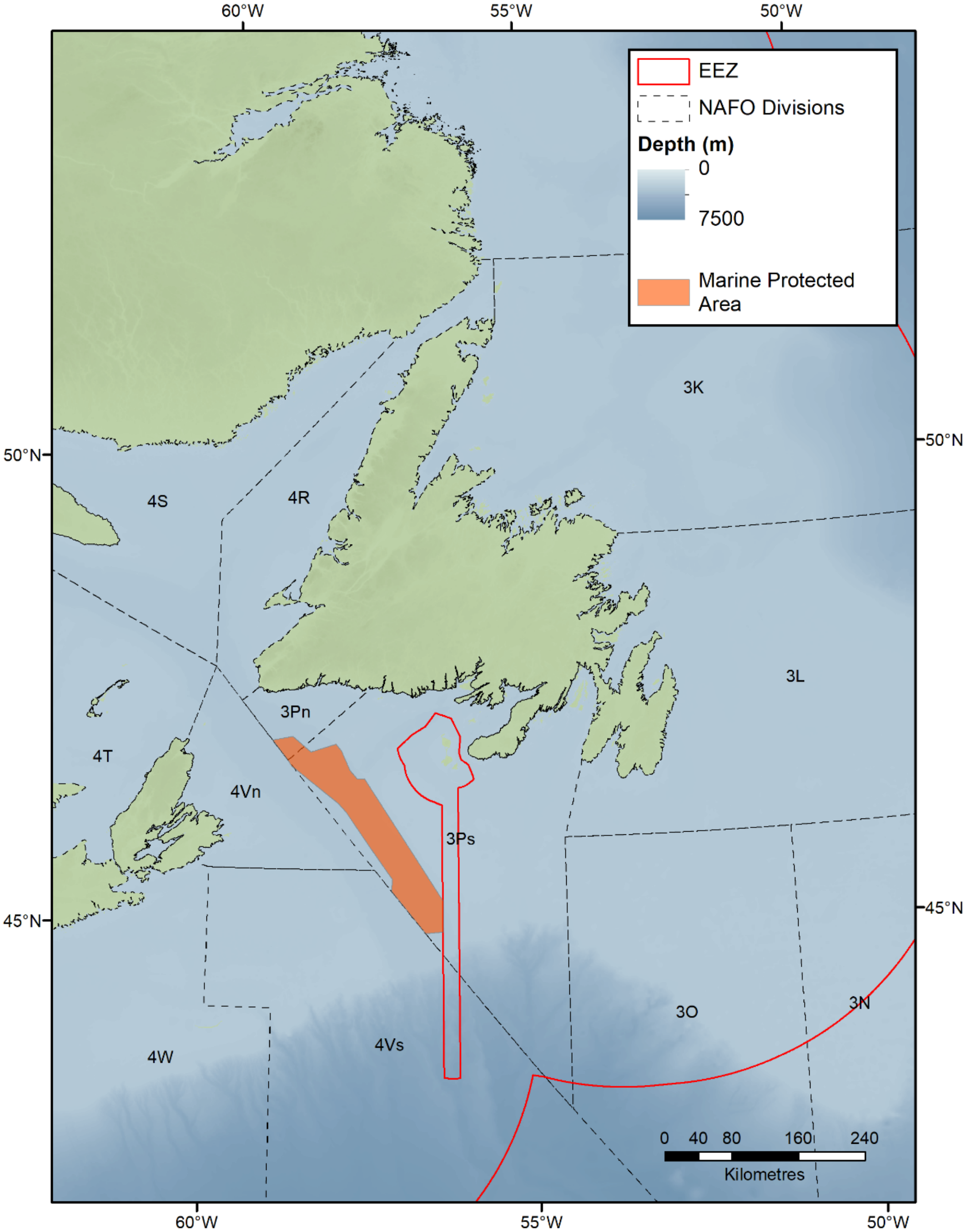


Figure 16: Location of the MPAs identified in the NL region where corals are a Conservation Objective (description of individual MPAs available in Table 2).

3. EXPLORATORY DRILLING IN NEWFOUNDLAND AND LABRADOR

The oil and gas industry has played an important role in the economy of NL since drilling began on the first exploratory wells in May 1966. As of January 2020, 172 exploration wells had been drilled, and 30 active exploration licenses had been issued within the region (C-NLOPB 2019a, 2019b) (Figure 17), providing the industry with opportunities to further their search for commercially viable deposits of oil and gas through the development of additional exploration wells (DNR 2019). The C-NLOPB has been the lead regulator of petroleum related activities in the Canada-NL Offshore Area since 1986.

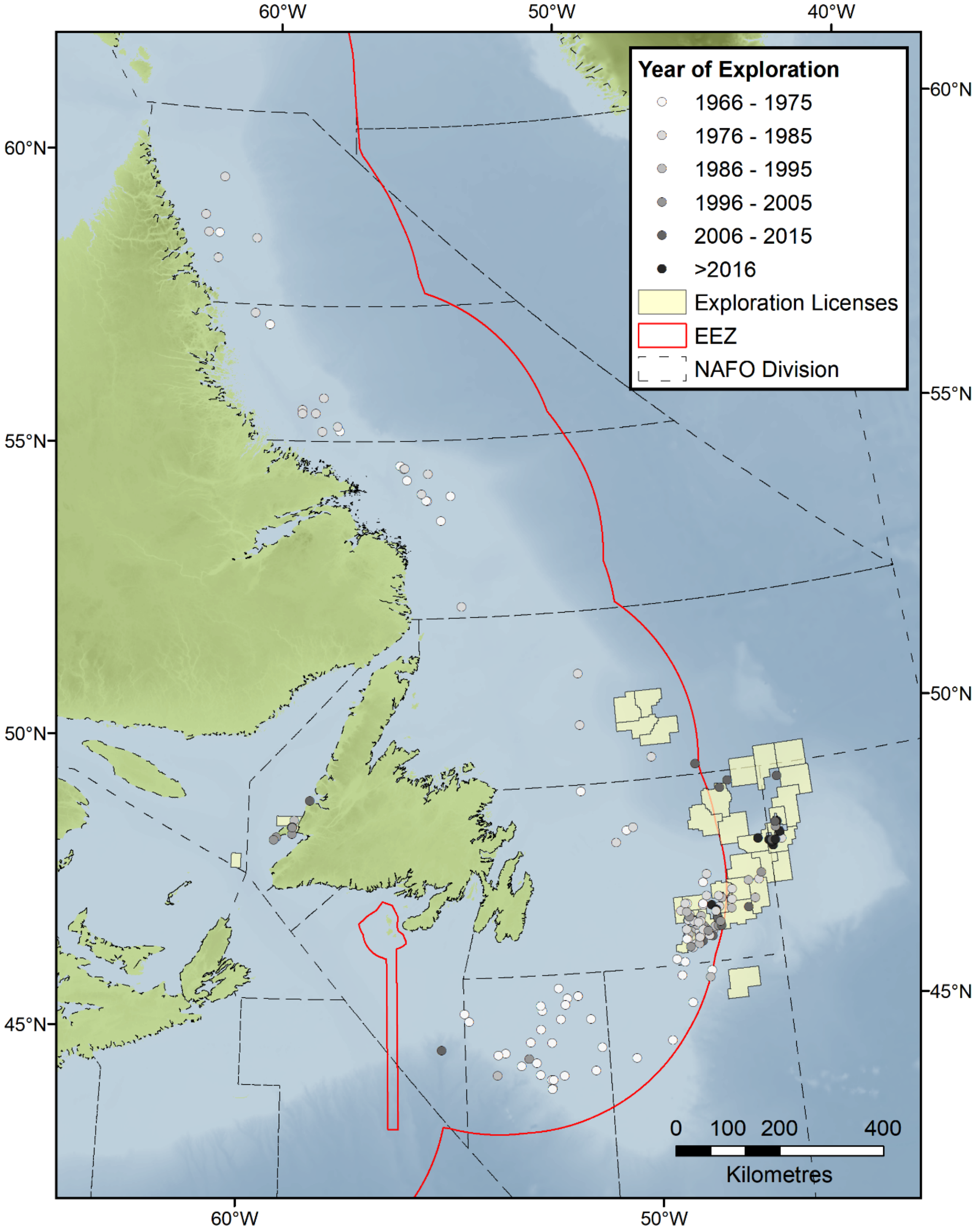


Figure 17: Location of exploration wells and licenses in the NL region downloaded as shapefiles from the C-NLOPB website in January 2020 (C-NLOPB 2019a).

3.1. ACTIVITIES WITH THE POTENTIAL TO IMPACT CORALS AND SPONGES

Exploratory drilling is conducted in areas where seismic surveys have indicated there is high potential for hydrocarbons to exist (Cordes et al. 2016). Drilling in these areas is required to confirm the presence of commercially viable hydrocarbon reserves that may be able to support production wells (DTI 2001), and the drilling activity will typically last 1–4 months (CAPP 2017). In most cases, offshore exploration wells, particularly those in deep water, are in areas of the marine environment where human impacts have historically been minimal, and little is known about the effects of anthropogenic activities (Ramirez-Llodra et al. 2011, Kark et al. 2015). Although the importance of deep-sea ecosystems is recognized, their value has not been well quantified (Thurber et al. 2014). Various routine activities associated with exploratory drilling have been found to impact deep-sea environments (Cordes et al. 2016), and existing literature indicates that, although some of the impacts are short-lived, effects may last longer for ecosystems containing fragile species such as cold-water corals (Cordes et al. 2016) and sponges (Jones et al. 2012, Hsing et al. 2013, Vad et al. 2018). In general, the main activities associated with exploratory drilling that can impact coral and sponge species include positioning, drilling, abandonment, and accidental events.

3.1.1. Positioning

In Atlantic Canada, exploratory drilling activities are typically performed from three main platforms: jack-ups, semi-submersibles, and drill ships (Figure 18). Jack-up platforms are typically restricted to water depths of 100 m or less, while semi-submersible platforms and drill ships are used in deeper waters. Jack-up platforms are equipped with three or four legs, approximately 15 m in diameter (Zahra and Rouhollah 2016), that support the platform directly on the sea floor. Semi-submersibles are supported by vertical columns sitting on pontoons which float below the surface of the water and stabilize the platform against wave action and, like drill ships, can be held in place during drilling operations through anchoring, or dynamic positioning (DP). Selection of a platform for drilling operations is largely based on water depth, drilling depth, weather and ice conditions, as well as the technical capabilities of the platform (CAPP 2017).

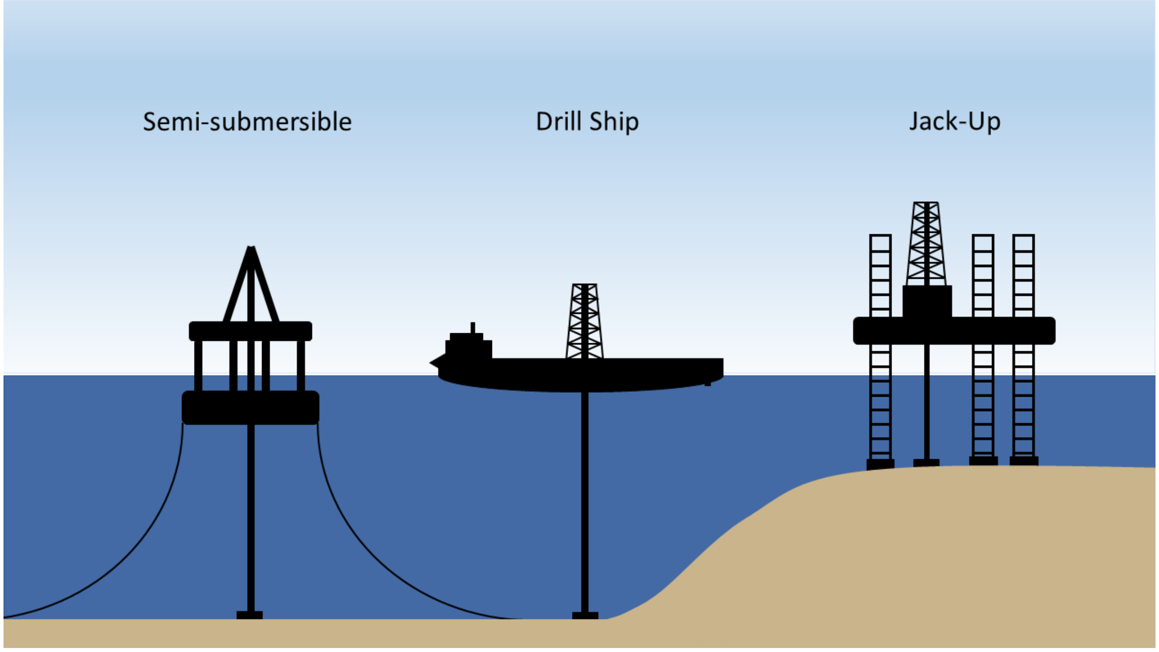


Figure 18: Drilling platforms used for offshore oil and gas exploration (Adapted from DTI 2001).

Depending on the drilling platform that is selected for use, the potential impacts on corals and sponges will vary. If a jack-up platform is selected as the most suitable platform, there is a risk of damage to species where the platform legs meet the seafloor, as well as in locations where additional stability is provided using spud cans (heavy structures attached to platform legs and driven into the seafloor) or by dumping gravel or rock around the base of the legs. Added stability is particularly important in areas with strong seabed currents that may cause sediment scour around the legs of the platform (DTI 2001). For these platforms, coral and sponge species in the area are at risk of coming in physical contact with the equipment, as well as being smothered or buried by rocks and/or re-suspended sediments.

In the NL region, semi-submersibles are normally anchored in place (Buchanan et al. 2003). The use of anchors is typically restricted to water depths ≤1,000 m, where 8–12 anchors are set on location by anchor handling vessels and attached to the platform via mooring lines (Yamamoto and Morooka 2005). For DP, an array of transponders (Figure 19) is placed on the seafloor and calibrations are performed to determine their exact positions relative to one another. Upon completion, the transponders communicate with each other as well as with the vessel to ensure it remains accurately positioned above the site throughout the drilling period. Like anchoring, there is potential for the individual transponders to come into physical contact with corals and sponges; however, the footprint of the impact would be much smaller.

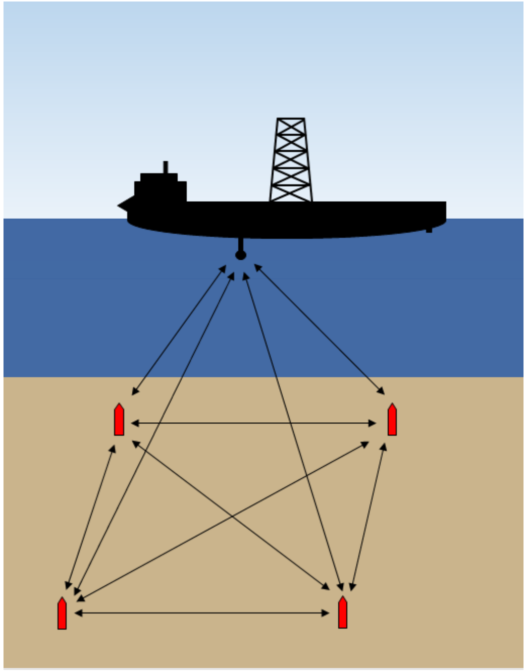


Figure 19: Illustration of a calibrated transponder array being used to dynamically positioning a drilling platform.

3.1.2. Drilling

Drilling of exploration wells is conducted in two stages, top hole drilling and exploration drilling, as illustrated below in Figure 20.

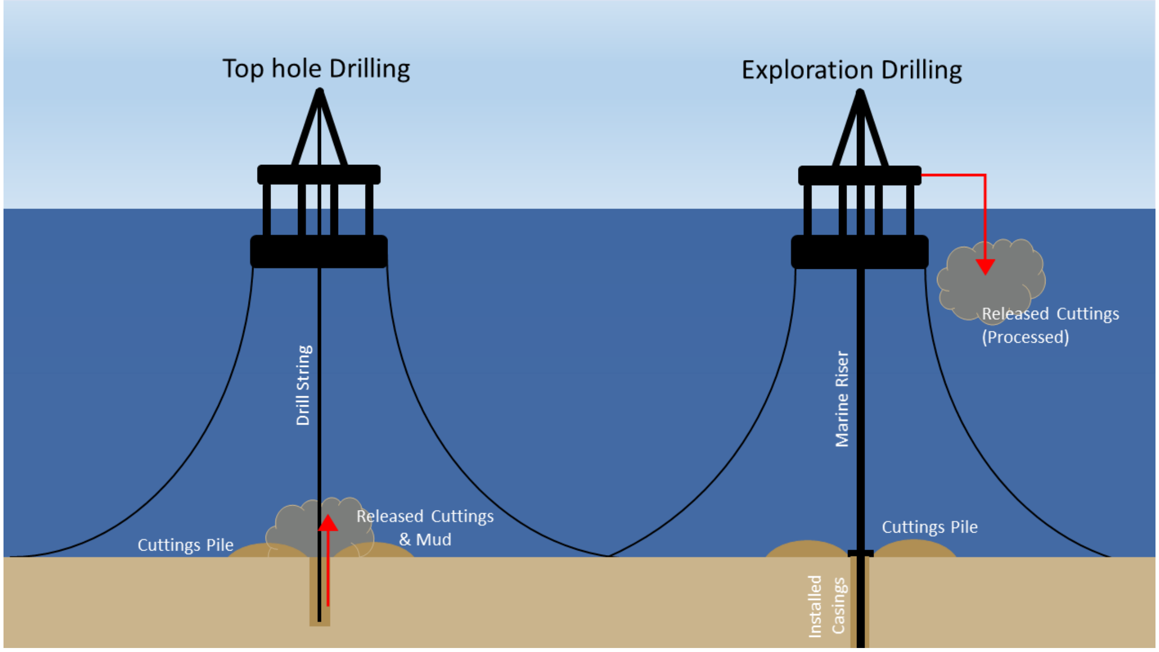


Figure 20: Stages of exploration drilling and associated release of cuttings and/or mud from semi-submersible drilling platforms (Adapted from Cordes et al. 2016).

3.1.2.1. Top Hole Drilling

Upon stabilization of a drilling platform at the exploration site, drilling can commence. Top hole drilling refers to the riserless drilling stage of the first two sections of the well (typically 36” and 26” diameter sections). This stage is performed before the marine riser (the structure which carries mud and cuttings created by drilling back to the platform for processing) has been installed (Figure 20). It contains the widest sections of the well, typically measuring ≤90 cm (~35 inches) in width, with subsequent sections progressively decreasing in size (DTI 2001). Because this portion of the well is installed before the marine riser is in place, cuttings, drilling fluids, and excess cement are deposited directly on the seafloor, forming a cuttings pile surrounding the well bore (Cordes et al. 2016). The specific makeup of drill cuttings will vary on a site-to-site basis, but will typically contain heavy metals, barite, bentonite, hydrocarbons, organic contaminants, and radioisotopes (Lakhal et al. 2009). This phase of drilling poses risks to corals and sponges as a result of direct physical contact with the drilling equipment, exposure to drilling muds and associated chemicals, as well as high levels of sediment resuspension, particularly when water jetting (the application of water at high pressures used to disturb sediment structure) is used (DTI 2001). Coarser particles settle out relatively quickly near the drill site to form thicker layers of deposition, while finer particles are transported further away by local currents being deposited more thinly over a larger area (Pivel et al. 2009). Once this section of the well is complete, a conductor pipe is installed and cemented into place to prevent the sides of the well from caving in. When the cement has set, a blow-out preventer (BOP) is installed, and the wellhead is connected to the platform via a marine riser (DTI 2001).

3.1.2.2. Exploration Drilling

Subsequent sections of the well are completed using a drill-bit, which runs from the platform to the well through the marine riser (Figure 20). As the drilling progresses, used mud and generated cuttings are circulated from the well to the platform through the riser for separation and treatment. Risks to corals and sponges in this stage of drilling are considered lower than during top hole drilling, as cuttings are treated prior to their release into the environment, and muds are held in a contained system.

3.1.2.3. Cement Application

After each section of the well is completed, the drill bit is removed, and a casing is put in place to provide structural support for the walls of the well. Cement is added inside the casing, followed by a plug. Mud applied behind the plug pushes it down in the casing, subsequently forcing the cement to the bottom of the well and into the annulus (area between the outside of the casing and the wall of the well) where it sets (DTI 2001). The most common plugging material is known as Portland Cement, which is primarily made up of calcium hydroxide and various silicate phases, but also contains additives (Vrålstad et al. 2019). Compared to typical marine conditions, Portland Cement is highly alkaline and some of its additives are known to be toxic to marine life, including corals and sponges (EPA 2002, Lukens and Selberg 2004, Perkol-Finkel and Stella 2014).

3.1.2.4. Injection of Drilling Mud

During the drilling process, drilling muds are used to lubricate and cool the drill bit, carry cuttings to the surface, and control pressure in the well (CAPP 2017). Drilling muds fall into three main classes depending on their make-up, which include: oil-based (OBM), water-based (WBM), and synthetic-based (SBM). In Atlantic Canada, all exploratory drilling is conducted using either WBMs or SBMs as they are less toxic than OBMs (Buchanan et al. 2003); however, documentation indicates that enhanced mineral oil-based muds (EMOBM) or OBMs may be used in place of SBMs in cases where there are sufficient technical justifications (AMEC 2014, C-NLOPB 2019c). Numerous chemicals are added to these muds so they maintain the proper chemical and physical properties (Breuer et al. 2004), and existing research has shown that they can negatively impact benthic species near drill sites (Trannum et al. 2010, Bakhtyar and Gagnon 2012, Edge et al. 2016). Effects of OBMs have been documented several kilometers from the well (Ellis et al. 2012), while SBMs have been observed to affect benthic communities within a radius of 500 m (Trannum et al. 2010). In contrast, WBMs are mostly documented to have impacts within 100 m of the drill site (Currie and Isaacs 2005, Trannum et al. 2006), although extreme cases have documented effects up to 2,000 m from the well site (Continental Shelf Associates 1989).

3.1.2.5. Release of Drill Cuttings

Other than when the top hole section of the well is being drilled, cuttings from the drilling operations are brought to the platform via the marine riser. If WBMs are being used, spent and excess mud and cuttings can be released without treatment. However, if SBMs or EMOBMs are being used, the cuttings will be separated from the drilling mud (which is recycled), treated, and may be released according to the offshore waste treatment guidelines (OWTG) regulated by C-NLOPB (C-NLOPB 2019c). Although not currently used in the NL region, the use of OBMs may be approved under exceptional circumstances (C-NLOPB 2019c). If OBMs are used, cuttings are either reinjected or retained and brought to shore for disposal (C-NLOPB 2019c). Depending on the depth of the drill site, the strength of currents in the area, and the type of drilling mud being used (Nexen Energy ULC 2019), drill cuttings released from the platform can be rapidly dispersed in the water column or may accumulate below the platform (Breuer et al. 2004). Burial and smothering are the main risks to corals and sponges as a result of this activity; however, remnants of chemicals on the treated cuttings may also impact these species. Because cuttings piles are resistant to chemical change it is possible that future disturbances may result in a source of contamination even after the site is abandoned (Brakstad and Ramstad 2001, Breuer et al. 2004).

3.1.3. Abandonment

Once the well has been drilled and tested, a decision is made whether to move forward and develop a production well. If production is not feasible, the well will be sealed to prevent fluids from within the reservoir from moving up to the surface and contaminating the surrounding environment (NPC 2011). The seal will be comprised of a cement plug up to 100 m long or a series of smaller plugs (CAPP 2017). During abandonment, any equipment installed on the seafloor will be removed and, depending on the depth of the well, the casing may also be cut below the seabed as per current Newfoundland Offshore Petroleum Drilling and Production Regulations (SOR/2009-316). During this process, cuttings and sediments contaminated during the drilling process will be re-suspended, and there is a further risk of exposing the surrounding benthic community to toxic materials within the cement used to plug the well.

If used, the retrieval of anchors will also take place during the abandonment stage. Using the grappling approach, a grappling anchor is dragged 100–150 m along the seabed to hook onto the pennant, the anchor chain is lifted from the seabed, and the anchor is retrieved (DNV 2013). Such an approach risks equipment coming into physical contact with corals and sponges, and results in the resuspension of sediments, possibly containing toxic material deposited during drilling operations (e.g. drilling muds, cuttings, produced water). A less destructive approach involves the use of an ROV to attach an anchor handling vessel directly to the pennant, eliminating the use of a grappling anchor and reducing the likelihood of physical damage and the amount of re-suspended sediment (DNV 2013).

3.1.4. Accidental Events

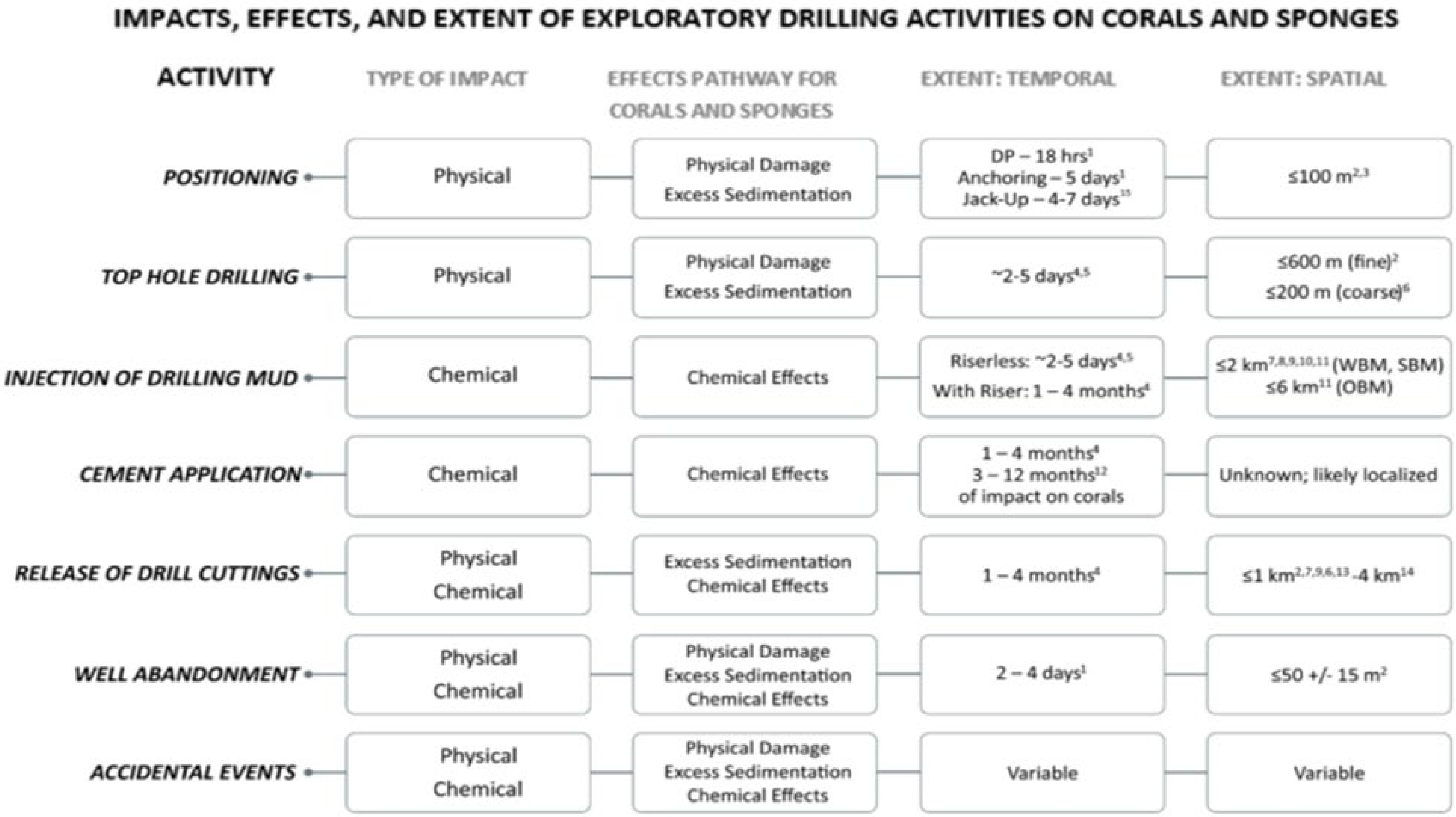
Due to the nature of exploratory drilling activities, there is a possibility that accidental events with the potential to impact coral and sponge species may occur. There is particular concern for operations in the NL region because of the harsh weather conditions that exist here and seasonal presence of ice. Reports published by the International Association of Oil and Gas Producers (OGP) indicate that the risk of accidental blow-outs is highest during the exploratory drilling phase (OGP 2010, 2019), and reviews of offshore oil and gas incidents in the Arctic and other ice-prone seas found that nearly 12% of all incidents on record occurred during this phase (Necci et al. 2019). While the causes of accidents occurring during the exploratory drilling phase are numerous, they can be broadly classified as resulting from: extreme weather conditions, ice events, human error, procedural error, and/or equipment failure (Stantec Consulting 2018).

While the most prominent concern associated with exploratory drilling is the accidental release of oil from the well, any incident which results in physical or chemical contact, or exposure to excess sedimentation, could pose risks to coral and sponge species. Physical damage, and in some cases damage from excess sedimentation, could occur as a result of unexpected equipment grounding (e.g. drilling platform), objects being dropped onto the seafloor (e.g. BOP stack), and failure of anchor and/or mooring lines (Necci et al. 2019, Yoklavich 2015). Alternatively, accidental chemical exposure could be related to the release of drilling mud such as SBMs (C-NSOPB 2019), or the release of oil into the environment (e.g. blow-out). In the event of an oil spill the application of chemical dispersants also poses a risk to coral and sponge species (DeLeo 2016).

For the purpose of this report, accidental events were not thoroughly investigated as they were not included in the terms of reference for this advisory process.

3.2. ANTICIPATED EFFECTS AND SEVERITY FOR CORALS AND SPONGES

Each of the activities described in the previous section are associated with various potential effects on coral and sponge species. The severity of these impacts varies in time and space and are likely to be worse in areas where exploratory wells sites are located near one another. This would be the result of cumulative impacts, where effects of different activities are combined over time. At present, limited research exists on the time required for coral and sponge species within the NL region to recover to pre-exploration conditions when impacted by exploratory drilling activities; therefore, the temporal impacts outlined in Figure 21 indicate the duration of individual activities in an exploratory drilling campaign, rather than the estimated time for recovery. The life history characteristics of coral and sponge species indicate that recovery of individuals and communities could take hundreds of years, suggesting that the true temporal impacts of exploratory drilling on these communities could be quite severe (Cordes et al. 2016). There has been very little work completed on cumulative impacts on corals and sponges. As a result, these impacts are not captured within Figure 21.



IMPACTS, EFFECTS, AND EXTENT OF EXPLORATORY DRILLING ACTIVITIES ON CORALS AND SPONGES

ACTIVITY	TYPE OF IMPACT	EFFECTS PATHWAY FOR CORALS AND SPONGES	EXTENT: TEMPORAL	EXTENT: SPATIAL
POSITIONING	Physical	Physical Damage Excess Sedimentation	DP – 18 hrs[1] Anchoring – 5 days[1] Jack-Up – 4-7 days[15]	≤100 m[2,3]
TOP HOLE DRILLING	Physical	Physical Damage Excess Sedimentation	~2-5 days[4,5]	≤600 m (fine)[2] ≤200 m (coarse)[6]
INJECTION OF DRILLING MUD	Chemical	Chemical Effects	Riserless: ~2-5 days[4,5] With Riser: 1 – 4 months[4]	≤2 km[7,8,9,10,11] (WBM, SBM) ≤6 km[11] (OBM)
CEMENT APPLICATION	Chemical	Chemical Effects	1 – 4 months[4] 3 – 12 months[12] of impact on corals	Unknown; likely localized
RELEASE OF DRILL CUTTINGS	Physical Chemical	Excess Sedimentation Chemical Effects	1 – 4 months[4]	≤1 km[2,7,9,6,13] -4 km[14]
WELL ABANDONMENT	Physical Chemical	Physical Damage Excess Sedimentation Chemical Effects	2 – 4 days[1]	≤50 +/- 15 m[2]
ACCIDENTAL EVENTS	Physical Chemical	Physical Damage Excess Sedimentation Chemical Effects	Variable	Variable

Figure 21: Impacts, Effects, and Extent of Exploratory Drilling Activities on Corals and Sponges. (Note: Temporal severity provides information on the length of time an activity will take to complete; Spatial severity provides information on the area which will likely be impacted by the activity).

[1]Statoil 2017, [2]DNV 2013, [3]Cordes et al. 2016, [4]CAPP 2017, [5]NSB Energy Consulting 2016, [6]Jones and Gates 2010, [7]Neff 2005, [8]Tenningen et al. 2011, [9]Pivel et al. 2009, [10]Paine et al. 2014, [11]Ellis et al. 2012, [12]Lukens and Selberg 2004, [13]Bakke et al. 2013, [14]Lepland et al. 2008 [15]EnCana Energy Corporation 2002.

4. IMPACTS OF EXPLORATORY DRILLING ON CORALS AND SPONGES

As exploration for oil and gas expands in offshore NL, the potential for interactions with coral and sponge species grows. Globally, the impacts of exploratory drilling on various benthic species and communities have been relatively well studied and largely suggest that exposure to exploratory drilling leads to reductions in the abundance, biomass, and diversity of benthic macrofauna (Daan et al. 1994, Hurley and Ellis 2004, Santos et al. 2010, Trannum et al. 2010, Ellis et al. 2012, Gates and Jones 2012, Paine et al. 2014), with some research highlighting an overall loss of suspension feeders (Ellis et al. 2012). However, studies documenting specific impacts on cold-water coral and sponge species and communities are more limited, mostly originating in Norway and generally focusing on the reef forming cold-water coral *Lophelia pertusa* (Purser and Thomsen 2012, Bakke et al. 2013, Larsson et al. 2013), which has recently been placed in the genus *Desmophyllum* as *Desmophyllum pertusum* based on molecular evidence (Addamo et al. 2012, WoRMS S. Cairns 2019)[1].

The impacts of exploratory drilling on corals and sponges can be classified into three types of disturbances:

- Physical (e.g. platform installation (including anchors), top hole drilling, equipment placement, well abandonment)
- Sediment (e.g. anchoring activities, top hole drilling)
- Chemical (e.g. cement, drill cuttings)

In general, these disturbances have been found to impact species behaviour, fitness, and survival (Allers et al. 2013, Larsson et al. 2013, Lak et al. 2015); however, specific impacts and responses to these disturbances vary by species (Ragnarsson et al. 2016).

4.1. IMPACTS ON CORALS

Cold-water corals are known to be long-lived, slow growing, fragile, and to exhibit variable rates of recruitment, making them particularly vulnerable to anthropogenic activities (Roberts et al. 2009). Physical damage and/or dislodgement caused by surface disturbances (e.g. drill, wellhead, mooring lines, anchors) are likely to result in mortality (Malecha and Stone 2009, Clark et al. 2016, Pierdomenico et al. 2018). Although this impact is spatially limited, recovery is typically prolonged (Cordes et al. 2016). In areas where corals have been exposed to physical damage as a result of bottom trawling, studies indicate that, even after extended periods of time, recolonization is limited or non-existent (Freiwald et al. 2004, Althaus et al. 2009, Williams et al. 2010, Neves et al. 2015, Huvenne et al. 2016).

For species that sustain injuries, recovery, if possible, can be complex. Henry and Hart (2005) showed that after mechanical damage, regeneration for small coral species varied depending on the morphological complexity of the species, and genotype. For corals that did regenerate after mechanical damage, consequences include impaired somatic growth, reductions in sexual reproduction, as well as decreased abilities of defense, competition, and recognition of conspecifics (Henry et al. 2003, Henry and Hart 2005, Malecha and Stone 2009). There is also potential for the severity of impacts to increase with the progression of ocean acidification. Research has shown that the changes in coral structure resulting from increased levels of

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[1] Due to the vast amount of literature still using the original name, the authors have chosen to use the name *Lophelia pertusa* throughout this paper.

carbon dioxide (CO_2) reduces overall strength, making them more susceptible to mechanical damage (Hennige et al. 2015, Roberts et al. 2006). Furthermore, in environments where food is limited, or where organisms have pre-existing injuries, regeneration may be even less successful (Henry and Hart 2005). This could pose significant problems in areas where species are exposed to exploratory drilling, where increased sedimentation has been found to reduce the ability of corals to feed (Liefmann et al. 2018) and in some cases could lead to polyp mortality (Gass and Roberts 2006, Brooke et al. 2009, Liefmann et al. 2018).

Compared to naturally eroded sediments, those generated during drilling are found to have rougher edges (Kutti et al. 2015), making them more likely to cause physical damage to coral species. In general, most of the sediment associated with exploratory drilling (e.g. drill cuttings) settles within 1 km from the site of exploration (Roberts et al. 2006). While visible sedimentation seldom extends further than 100 m from the point of discharge (Gates and Jones 2012), concentrations of some drilling chemicals (e.g. Barium) have been detected in surface sediments up to 4 km away from drilling sites (Lepland and Mortensen 2008). Redistribution of sediment is considered the primary risk to coral species near exploratory drilling sites (Roberts et al. 2006), yet the effects of sedimentation on cold-water corals remain poorly investigated (Larsson and Purser 2011). Most studies that exist focus on shallow-water coral species, and on one specific species of framework-forming scleratinian coral from the Northeast Atlantic (*Lophelia pertusa*). The most commonly reported effects of excess sedimentation include smothering (Larsson and Purser 2011), physical damage (Pollock et al. 2014), reduced feeding and energy availability (Brown and Bythell 2005, Liefmann et al. 2018), reductions in suitable habitat for larvae settlement (Larsson et al. 2013, Liefmann et al. 2018), mortality (Larsson and Purser 2011, Järnegren et al. 2017), and general reductions in coral coverage (Steinhauer and Imamura 1990). The impacts on larvae are considered most severe, with larvae experiencing elevated levels of mortality because of sediment clogged cilia, which impacts their ability to move (Järnegren et al. 2017, 2020). Depending on the time of the year, excess sedimentation also has the potential to impact connectivity and disrupt natural larval dispersion, although this has not been thoroughly investigated in the NL region (Kenchington et al. 2019b).

Throughout the stages of exploratory drilling various chemicals are also released from the drill site and/or platform in the form of drilling mud, contaminated drill cuttings, and concrete. Exposure to these chemicals also pose potential risks to coral, but they vary depending on the species present as well as the chemicals used, and concentrations being released. Today, WBMs are most common because they have been demonstrated to pose little or no risk to the environment (Neff 2010); however, evidence indicates that they do impact some coral species. A study by Raimondi et al. (1997) examined the effects of exposure of WBM on cup coral species (*Paracyathus stearnsii*) and found that exposure to both low (0.002 mg/L) and high (200 mg/L) concentrations of WBM (realistic of environmental concentrations) resulted in mortality, tissue loss, and viability, impacting survivorship. For other species, exposure to WBM led to decreases in overall coral coverage (Steinhauer and Imamura 1990). Buhl-Mortensen et al. (2010) found no immediate significant behavioral differences or changes in feeding rates for *Lophelia pertusa* when exposed to cuttings contaminated with WBM, though long-term impacts were not investigated and could not be ruled out. More recent work by Järnegren et al. (2020) indicates that bentonite and barite can alter behaviours (e.g. swimming speed), increase mortality, and lower recovery rates of *Lophelia pertusa* larvae. Specifically, the work showed that when exposed to the highest experimental concentration of bentonite, ~35% of eight-day old larvae experienced clogged cilia which impacted their ability to swim, while a small percentage died. Approximately 18% of 21-day old larvae experienced clogging of their cilia when exposed to experimental bentonite concentrations, while ~26% died as a result of exposure. For both age classes, recovery was limited after 24 hours. The impacts of barite were generally less severe, with ~6% of eight-day old larvae experiencing clogging and most larvae generally recovering within a 24-hour period.

While OBM are only approved for use under exceptional circumstances in the NL region (C-NLOPB 2019c), compared to WBM, they generally lead to more severe impacts, with effects typically extending further from the site of exploration (Figure 21). As a result, the use of OBMs is presently restricted in many jurisdictions (Cordes et al. 2016). In general, observed changes in community structure because of exposure to OBMs are related to the total hydrocarbon content (THC), concentrations of barium and strontium, as well as the presence of zinc, copper, cadmium, and lead (Ellis et al. 2012). Existing research on the impact of OBMs on corals is limited and largely restricted to shallow-water species. Thompson and Bright (1980) found that several of the seven species they studied died after exposure to OBM, while six of the seven experienced significant polyp retraction. Dodge (1982) exposed a tropical reef building coral, *Orbicella annularis* (published as *Monastratea annularis*), to various concentrations of OBM (0, 1, 10, and 100 ppm µl/L) and observed impairments of coral skeletal growth and, at the highest experimental concentration, potential interferences with the coral's ability to reject sediment.

Approximately 30 years ago, SBMs were developed to combine the technical capabilities of OBMs with the low persistence and toxicity of WBMs. They are often used when WBMs are unsuitable for certain drilling activities (Neff et al. 2000). To date, no studies have been published that examine the effects of SBMs on coral species. However, a review by Ellis et al. (2012) indicates that exposure to SBMs has been linked to decreases in the abundance of various benthic species. The findings are thought to result from nutrient enrichment caused by SBMs, which represent a carbon source, and may lead to oxygen depletion in the surrounding area (Ellis et al. 2012).

Portland cement applied during the installation of casings may also be released on the seafloor during exploration. This product is highly alkaline and has been linked to reduced rates of recruitment of shallow-water coral species, when compared to less alkaline concrete mixtures (Perkol-Finkel and Stella 2014). Nonetheless, other studies have found that corals will settle on alkaline surfaces (Burt et al. 2009), suggesting that the presence of hard substrate could potentially expedite recovery after exploratory drilling has ended (Gass and Roberts 2006, Macreadie et al. 2011). Several examples of this exist in shallow-water environments where concrete has been used to create artificial reefs in support of reef rehabilitation (Hueckel et al. 1989, Clark and Edwards 1994, Burt et al. 2009). However, the benefit of providing newly created substrate for larval settlement is unlikely to outweigh the various potential impacts that exploratory drilling processes might have on coral and sponge species.

4.2. IMPACTS ON SPONGES

Like cold-water corals, the three-dimensional structures created by deep-sea sponges can provide suitable habitat for other species, with sponge grounds supporting higher amounts of biodiversity than areas without sponges (Beazley et al. 2013a, Hawkes et al. 2019). Furthermore, because of their presumed slow growth, longevity, and infrequent reproduction, they are known to be vulnerable to physical damage (Klitgaard and Tendal 2004, Vad et al. 2018), which has been documented to lead to rapid tissue death and disease (Büttner and Siebler 2013). Those most at-risk to damage are soft-bodied sponges, or those with low spongin (protein) content (Schönberg 2016). Existing literature indicates that physical damage to sponges can result in decreasing sponge abundance (Bell et al. 2015a), with the effects of drilling detectable up to 10 years after it has ended (Jones et al. 2012). However, the effects of clean cuts are considered less damaging, with some species capable of making repairs in a just a few days (Büttner and Siebler 2013). Dunham et al. (2015) showed that physical damage resulting from the installation of power transmission cables at 68 m depth led to 100% mortality of glass sponges below the cables, as well as a 15% mortality rate within 1.5 m of the cable 3.5 years after the installation was completed.

In combination, physical damage and the subsequent sedimentation of drill cuttings from oil and gas exploration have been found to reduce the megafaunal density of sponge grounds by 92.3% (Jones et al. 2006). A study by Gates and Jones (2012) found that once dominant sponges (*Phakellia* sp. and *Mycale* sp. – also found in the NL region) became rare after drilling operations led to the burial of their habitat. For deep-sea sponges, documented impacts of sedimentation include reduced respiration and metabolic rate (Tjensvoll et al. 2013, Kutti et al. 2015), arrest in feeding behaviour, and chamber clogging (Tompkins-Macdonald and Leys 2008, Bell et al. 2015b). Findings suggest that rates of recovery vary between species (Vad et al. 2018), but also with sediment size (fine sediments being more detrimental), as well as depth and duration of burial (Schönberg 2016). Compared to natural sediments, exposure to drill cuttings from exploratory drilling activities has been found to decrease survival rates of *Thenea muricata* (H. Rapp pers. comm.). For shallow-water sponge species, burial will lead to mortality after just days (Wulff 2008). Juvenile sponges are particularly vulnerable to smothering, as their larval phase involves flattening and spreading, increasing their surface area (Leys and Degnan 2002, Maldonado 2008). In response to excess sedimentation, sponges have been found to produce mucus (Bannister et al. 2012, Schönberg 2016), stop pumping (Tompkins-MacDonald and Leys 2008, Grant et al. 2018, 2019), alter their respiration (Tjensvoll et al. 2013), reposition their osculum (Bell 2004), and/or exhibit coordinated contractions (Elliott and Leys 2007) to promote survival. Each of these activities requires excess energy expenditure and would likely have a negative impact if they were required for long periods of time (Bannister et al. 2012).

Few studies have investigated the impact that exposure to drilling muds has on sponge species. Those that do exist have found that sponge density and diversity is reduced in areas near drilling sites (100–200 m radius) where drilling muds are found in greatest concentrations and indicate that the impacts at these sites persist over time (Gates and Jones 2012, Jones et al. 2012). One study of *Geodia baretti* found that exposure to WBMs impacted the species at concentrations as low as 30 mg total suspended solid (TSS)/L, reducing lysosomal membrane stability and compromising cellular viability (Edge et al. 2016). However, the toxicity of the muds was lower when the exposure was intermittent instead of continuous (Edge et al. 2016).

There is very limited information on the effects of exposing sponge species to cement. One study by Gilliam et al. (2008) attempted to re-secure dislodged sponge fragments with cement but found that tissues died when they came in contact with the cement, preventing successful attachment and growth. However, this study only looked at the impact on one species of sponge (*Xestospongia muta*) off the coast of Florida.

4.3. IMPACTS ON CORAL AND SPONGE SPECIES IN THE NL REGION

The specific impacts of exploratory drilling on coral and sponge species known to exist in the NL region have not been well studied to date. As a result, some of the information contained within the following tables is associated with other activities known to cause impacts similar to exploratory drilling (e.g. sediment redistribution, burial, mechanical contact), activities in locations outside the Northwest Atlantic, or activities that only partially address the potential impacts of exploratory drilling. Proxies for exploratory drilling were selected based on the level of sedimentation, physical damage, and/or chemical exposure associated with them. It is possible that the impacts described below could vary depending on the specific activity taking place, as well as the geographic location of the activity. Because of this, potential data gaps have been addressed in footnotes following Table 3.

Table 3: Documented effects of exploratory drilling and other activities (e.g. trawling, sedimentation) on coral and sponge species known to exist in the NL region. Note: Some of the documented effects in the table describe species which have not been reported in the NL region, but fall within a genus which has been documented here.

Group	**Species**	**Documented Effect**	**Effects Pathway**	**Depth (m)**	**Activity**	**Location of Research**
Large Gorgonian	*Paramuricea* spp.	Exposure to oil from Deepwater Horizon resulted in branch loss, with impacts remaining higher than reference sites for 7 years (Girard and Fisher 2018)[1].	Chemical Exposure	1,050–1,850 m	Oil Exposure	Gulf of Mexico
Large Gorgonian	*Primnoa resedaeformis*	Increased food intake and significant loss of polyps under increased sedimentation; sharp particles <10 µm (similar to those produced during drilling activities) became embedded into the corals tissues and have the potential to lead to necrosis and/or disease (Liefmann et al. 2018)[2].	Sediment Resuspension	Laboratory Experiment: specimens collected at 94–113 m	Mining	Norway
Large Gorgonian	*Paragorgia arborea*	Purser (2015) showed no detectable change in the abundance or mortality of *P. arborea* near drill sites (<2 km) up to 1 year after the drilling activities were completed when WBMs were used[3].	Sediment Resuspension	350 m	Exploratory Drilling	Norway

Group	Species	Documented Effect	Effects Pathway	Depth (m)	Activity	Location of Research
Cup Coral	*Desmophyllum dianthus*	Although the exact impacts of sedimentation are not well-known, the preferred habitat (near vertical walls or on the underside of rock ledges) and physical attributes (downward facing polyps) of this species indicate that it is sensitive to sedimentation (Försterra et al. 2005)[7].	Sediment Resuspension	<260 m	Natural Sedimentation	Chile
Sea Pen	*Halipteris* sp.	Malecha and Stone (2009) described dislodgment as the primary concern. Although this species (*Halipteris willemoesi*) has exhibited limited capacity to rebury and recover, the majority of those that succeed are subsequently dislodged without disturbance[4]. For specimens that were not able to recover, predation by nudibranchs was heightened.	Physical Damage	21–30 m	Trawling	Alaska
Sea Pen	*Funiculina quadrangularis*	In areas of high disturbance, the abundance of *F. quadrangularis* is reduced. They are considered more vulnerable to physical damage than other sea pen	Physical Damage	320–540 m	Trawling	Western Mediterranean & Southern Tyrrhenian Sea

Group	Species	Documented Effect	Effects Pathway	Depth (m)	Activity	Location of Research
		species which can withdraw into the sediment when disturbed. However, the species body flexibility provides some protection against physical disturbances (Pierdominico et al. 2018). Eno et al. (2001) showed that smothered or uprooted individuals were able to rebury and upright themselves in a few days. However, long-term survivability of the reburied individuals was not investigated.				
Sea Pen	*Funiculina quadrangularis* *Pennatula phosphorea* *Virgularia mirabilis*	Eno et al. (2001) showed that some smothered or uprooted individuals were able to rebury and upright themselves in a few days. However, long-term survivability of the reburied individuals was not investigated. The authors of the study noted that it is possible cumulative effects could lead to deteriorating conditions of the sea pens studied[5].	Physical Damage	14–20 m	Bottom Contact Fishing Gear	Great Britain

Group	**Species**	**Documented Effect**	**Effects Pathway**	**Depth (m)**	**Activity**	**Location of Research**
Soft Coral	*Duva florida*	Decrease in food consumption and altered behaviours (prolonged periods of contraction) when exposed to increased sedimentation; sharp particles <10 µm became embedded into the corals tissues which could lead to necrosis and/or disease (Liefmann et al. 2018)[2].	Sediment Resuspension	Laboratory Experiment: specimens collected at 174–188 m	Mining	Norway
Soft Coral	*Gersemia rubiformis*	Physical contact with subsea equipment which caused crushing of the studied colonies led to complete colony retraction, weakened body stalks, and the premature release and high mortality of brooded planulae. However, recovery from more localized injuries occurred in less than 30 days (Henry et al. 2003)[5].	Physical Damage	Laboratory Experiment: specimens collected at 10 m	Experimental Mechanical Disturbance	Northwest Atlantic
Black Coral	*Leiopathes* sp.	When exposed to 0.8, 7.9, and 25 ppm of oil, *L. glaberrima* responded with mucus production, tissue disintegration, and altered gene expression (DeLeo 2016, Ruiz-Ramos et al. 2017).	Chemical Exposure	Laboratory Experiment: specimens collected at 500 m	Oil and Dispersant Exposure	Gulf of Mexico

Group	Species	Documented Effect	Effects Pathway	Depth (m)	Activity	Location of Research
Sponge	*Geodia barretti*	Decreased pumping rates, reduced respiration, decreased metabolic activity (Kutti et al. 2015, Fang et al. 2018). Kutti et al. (2015) also found that finer particles exhibited greater effects on the metabolism of this species. Laboratory experiments have shown that individuals shut down when exposed to sediment concentrations of 100 mg/L but are able to recover quickly from short periods of exposure (Tjensvoll et al. 2013).	Sediment Resuspension	Laboratory Experiment: specimens collected at 200 m	Simulated Sedimentation	Norway
Sponge	*Haliclona* spp.	This species is considered to be well equipped for dealing with sedimentation due to its cylindrical shape (decreased surface area), apical osculum and exhalent jet, which prevent sediments from settling (Bell 2004, Schönberg 2016). It has been documented as one of the most dominant species at high sedimentation sites (Schönberg 2016). Still, research has shown that increased sedimentation can result in decreased growth	Sediment Resuspension	Laboratory Experiment	Simulated Sedimentation	Australia

Group	Species	Documented Effect	Effects Pathway	Depth (m)	Activity	Location of Research
		(Abdo et al. 2006, Pineda 2015) and even mortality (Pineda 2015)[8].				
Sponge	*Polymastia* spp.	This species appears better suited to areas with high sedimentation (Schönberg 2016). Field observations indicating the sponges' surface is often covered in a layer of sediment with exhalant papillae kept above the sediment to prevent smothering. The species is rare in clear-water sites (Bell and Barnes 2000a, 2000b).	Sediment Resuspension	0–30 m	Natural Sedimentation	Australia
Sponge	*Tethya aurantium*	This species has been observed rejecting necrotic tissue that resulted from sedimentation (Schönberg 2016)	Sediment Resuspension	N/A	Natural Sedimentation	N/A
Sponge	*Cliona* spp.	Field studies indicate that this species is capable of withstanding relatively high rates of natural sedimentation (Azzini et al. 2007)[9].	Sediment Resuspension	<10 m	Natural Sedimentation	North Vietnam
Sponge	*Phakellia ventilabrum*	Exposing *P. ventilabrum* to increasing concentrations of natural sediments and drill cuttings resulted in the	Sediment Resuspension	Laboratory Experiment: specimens	Exploratory Drilling	Norway

Group	Species	Documented Effect	Effects Pathway	Depth (m)	Activity	Location of Research
		upregulation of heat shock protein 70 (hsp70) and the enzyme nitric oxide synthase (NOS), suggesting that the species is impacted by elevated concentrations of both natural and anthropogenic particles similarly. However, natural sediments were incorporated into the sponge at a higher rate than sediments associated with drill cuttings, and high sediment concentrations within the sponges (<200 mg/g sponge) were linked to increased rates of respiration (Schuster 2013)[6].	Chemical Exposure	collected at 70–200 m		
Sponge	*Stylocordyla borealis*	This sponge develops its young internally and has a very low range of dispersion for the offspring (Sarà et al. 2002). Because of this, it would likely be difficult to recruit new sponges from other locations after the death of the species at drilling sites.	Sediment Resuspension	N/A	N/A	Antarctica
Sponge	*Mycale* sp.	Increased turbidity and sedimentation from storms	Sediment Resuspension	17–49 m	Natural Sedimentation	Jamaica

Group	Species	Documented Effect	Effects Pathway	Depth (m)	Activity	Location of Research
		led to reduced pumping rates (Reiswig 1971)				

[1] Effects observed for *Paramuricea* spp. were in relation to concentrations of oil from the 2010 Deepwater Horizon spill in the Gulf of Mexico. It is highly unlikely that the concentrations and temporal nature of oil associated with exploratory drilling would be equivalent to this.

[2] The impacts of sedimentation on *D. florida* and *P. resedaeformis* described by Liefmann et al. (2018) were documented for mine tailings. The shape and size of sediment generated by exploratory drilling could differ, resulting in varying degrees of impact on the species. This study was also conducted within a laboratory setting, which could influence the degree to which the specimens reacted to the treatments.

[3] Impacts described for *P. arborea* were documented during a drilling campaign using only WBMs. Should other drilling muds be used (OBM or SBM), different effects may be observed (Purser 2015). Furthermore, should corals be located nearer to the drill site, the concentration of re-suspended sediments would be higher than the 0–25 ppm outlined by Purser (2015), likely resulting in more severe impacts.

[4] Impacts resulting from physical damage described for *Halipteris* sp. was specific to *H. willemoesi. Halipteris* spp. from the NL region can reach 2.5 m in height and are likely not designed for reattachment.

[5] Physical contact with *F. quadrangularis* and *G. rubiformis* were studied in the context of bottom trawling activities. As a result, the damage to these species could differ and would likely be more localized for exploratory drilling. In addition, recovery rates of *G. rubiformis* are not likely reflective of other coral species, as they often occupy shallow waters where they are regularly exposed to mechanical stressors which suggests their fast recovery may reflect their specific adaptations to these environmental conditions.

[6] The recorded increase in hsp70 and NOS in response to sedimentation on *P. ventilabrum* may also be the result of the laboratory conditions the species was exposed to. During the experiment, water temperature was 2°C higher than the sponges' natural habitat.

[7] The specific effects of sedimentation on *D. dianthus* were not described by Försterra et al. (2005).

[8] Mortality observed under increased sedimentation for *Haliclona* sp. as described in Pineda (2015) was for an aquarium setting; results in natural settings may differ.

[9] Tolerance of *Cliona* spp. to sedimentation discussed in Azzini et al. (2007) was based on natural sediments from North Vietnam. As such, the ability to deal with increased sedimentation rates may be different in the NL region, particularly when exposure is to drill cuttings.

5. AVOIDANCE AND MITIGATION

Under Section 20 of the *Canadian Environmental Assessment Act* 2012 (replaced by the *Impact Assessment Act* on August 28, 2019), as well as the Memorandum of Understanding (MOU) between C-NLOPB and DFO, FFHPP provides expert advice on oil and gas activities to the Impact Assessment Agency of Canada (IAAC; formerly CEAA). In this capacity, FFHPP coordinates the departmental review of Environmental Impact Statements (EISs) submitted by proponents and provides advice on how best to avoid and/or mitigate the impacts that exploratory drilling activities might pose to coral and sponge species.

Mitigation measures are ideally identified and implemented in accordance with the widely accepted “mitigation hierarchy” of: (1) avoid; (2) mitigate; and (3) offset (recognizing that offsetting will not generally be compatible with benthic conservation objectives) (DFO 2019a). Previous DFO Science advice recommended a lower threshold of impact and a higher expectation of mitigation inside areas with defined benthic conservation objectives, as a higher vulnerability to anthropogenic activities is often inferred here or has been explicitly identified (DFO 2019d). Avoidance of impacts to these areas is the most effective mitigation measure available because it eliminates the potential for interactions between the activity and benthic components, minimizing the likelihood of serious or irreversible harm (DFO 2019d). Avoidance can have three components: spatial (move location, directional drilling), temporal (activity at a different time), and activity (reinjection or relocation of cuttings vs. direct discharge into the water column), although in general, spatial avoidance is considered the best option to avoid impacts to coral and sponge species. Where avoidance is not feasible, other mitigation measures may be effective for limiting impacts and would require consideration on a case-by-case basis (DFO 2019d).

In a review of the IAACs Regional Assessment of Offshore Oil and Gas Exploratory Drilling East of NL, DFO Science further recommended that special mitigations be applied in areas that are deemed special (e.g. VMEs, SiBAs, EBSAs) but are not currently protected by other management measures. While it was recognized that some of these special areas are already protected from some anthropogenic activities either fully or in part (e.g. MRs, VME closures; see Figure 22), it was recommended that mitigation measures pertaining to exploratory drilling activities be considered at the scale of the actual special areas, not at the scale of the protected portions (DFO 2020).

Further to these recommendations meant to protect aggregations of corals and sponges, protection standards have been developed by the Government of Canada for MPAs and MRs, in order to conserve sensitive and important parts of the ocean. For all federal MPAs, four key industrial activities are prohibited: oil and gas activities; mining; dumping; and bottom trawling. For MRs, activities proposed within these areas will be assessed on a case-by-case basis. Some activities may be allowed if they are consistent with the conservation objectives of a specific area but before any proposed activity can take place, the Minister of Fisheries, Oceans and the Canadian Coast Guard will need to be satisfied that any risks to the area have been avoided or mitigated effectively. Once oil and gas extraction begins in a MR, the portion of the oil and gas license or permit that overlaps with the MR will no longer count towards Canada’s marine conservation targets.

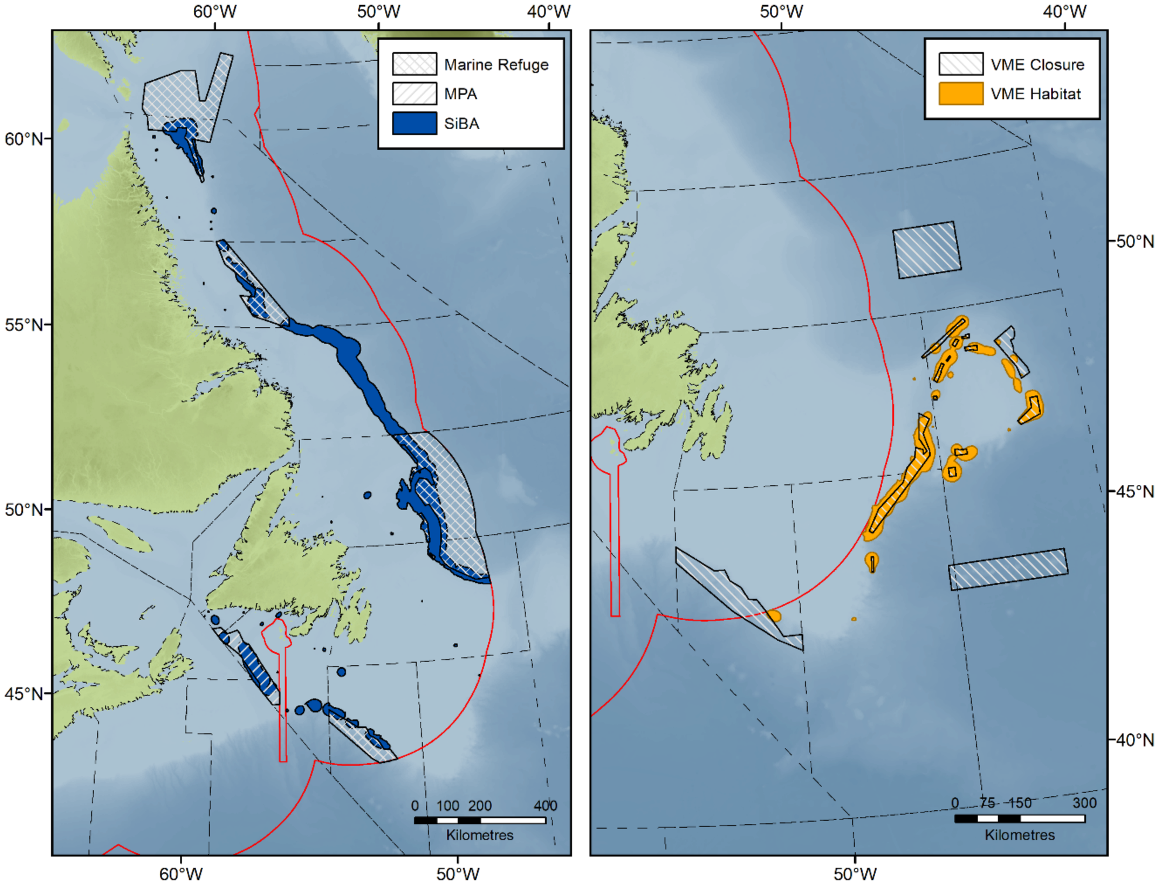

Figure 22: A comparison of the boundaries for Marine Refuges and MPAs with SiBAs (left panel) and VME Fisheries Closure Areas with VME habitats (right panel). The areas depicted here reflect those where corals and/or sponges were identified as Conservation Objectives or Key Features. All SiBAs and VME habitats are colored the same regardless of the conservation objective they represent.

Presently, if aggregations of habitat-forming corals and/or sponges are found within the study area, the primary advice is to relocate the wellsite. If that is not possible, mitigating the impact that the activities will have on these species is the recommended next step (CEAA 2019a). To build on this advice, a framework (Figure 23) was developed to assist in determining whether avoidance/mitigation is recommended at proposed drill sites. A series of proposed best practices for pre-drill surveys, avoidance and mitigation, and follow-up monitoring were compiled and are provided in Section 7 to support this framework.

In general, avoidance is recommended for all sites located within SiBAs and VMEs, and any areas where the zone of influence of the activity would overlap SiBA and VME boundaries. As per previous advice, this recommendation applies to the actual SiBA and VME habitat boundaries delineated through scientific processes, and not at the scale of the protected portions (i.e. MPAs, MRs, and VME closures) (see Figure 11 and Figure 22). Outside the boundaries of SiBAs and VMEs, avoidance/mitigation depends on the density of corals and/or sponges identified during the pre-drill surveys. For example, if a pre-drill survey identifies significant coral and/or sponge concentrations (i.e. above significant density threshold, discussed in section 5.1.3), site relocation should be still be the primary goal. However, if the proposed drill site falls within an area with corals and/or sponges, but the pre-drill survey indicates that concentrations are below the significant density thresholds (Section 5.1.3), various mitigation measures (Table 6, Table 7, Table 8) as well as enhanced follow-up monitoring programs (Table 9) are recommended.

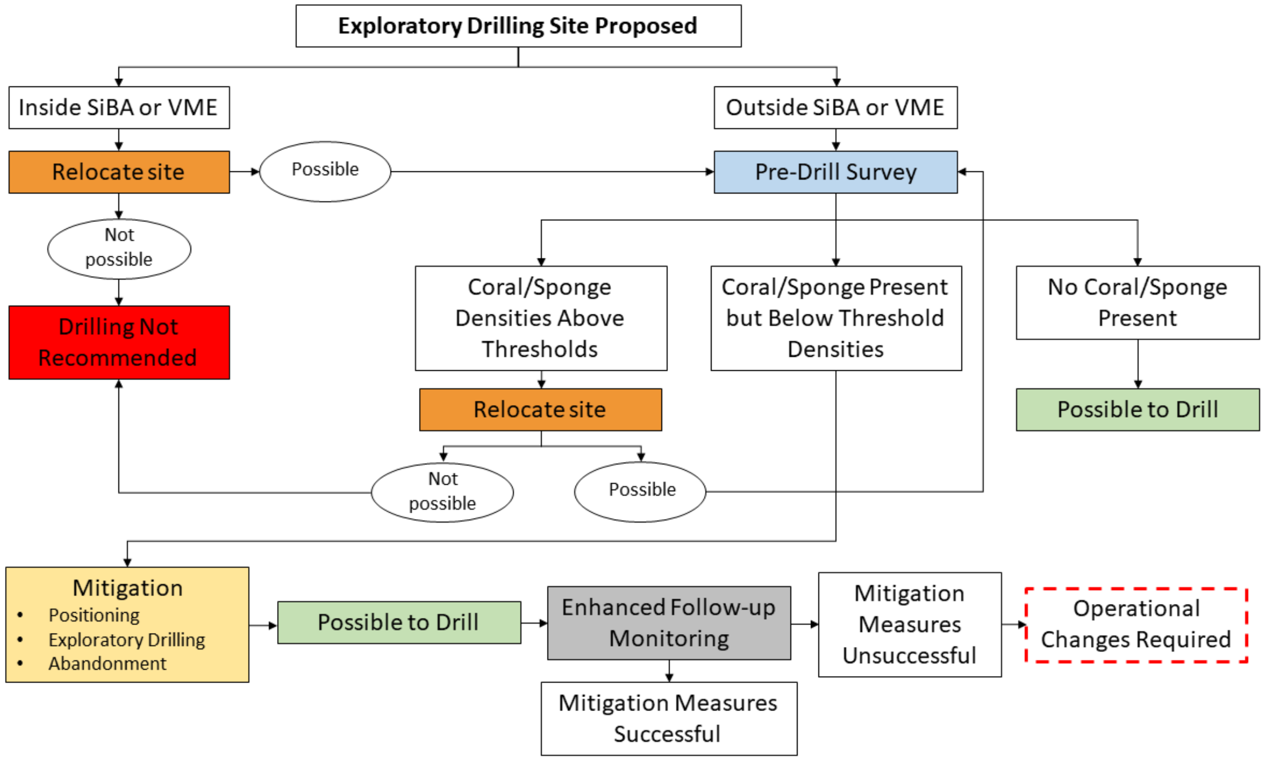

Figure 23: Decision-making framework for avoidance/mitigation of corals and sponges at proposed exploratory drill sites.

5.1. PRE-DRILL SURVEYS

Pre-drill surveys are meant to characterize the area surrounding the proposed well-site in order to identify whether aggregations of habitat-forming corals and sponges are present nearby. Results of these surveys are used to assess whether avoidance and/or mitigation measures are required throughout the drilling process. As a condition of authorization, drilling activities are prohibited from occurring within 100 m of a coral colony, defined by the C-NLOPB as either a *Lophelia pertusa* reef complex, or 5 or more large corals (>30 cm in height or width), within 100 m^2 (C-NLOPB 2018).

Present methodologies for pre-drill surveys in the NL region are based on aspects of the Norwegian Oil and Gas Authority (NOROG) guidelines outlined within the document: "*Monitoring of Drilling Activities in Areas with Presence of Cold Water Corals*" (DNV 2013), which focused primarily on attributes (e.g. size and concentration) specific to *Lophelia pertusa* reef systems and aggregations of gorgonian corals. While observations of living *L. pertusa* colonies have been reported in Nova Scotia (NS), where they have been extensively damaged by fishing (Gass and Willison 2005), and Southwest Greenland, where they do not form reef complexes, no living observations have been recorded in the NL region (V. Hayes, pers. comm.). Furthermore, the current guidelines do not consider many sea pens (e.g. *Pennatula aculeata*), small gorgonians (e.g. *Acanella arbuscula*), or sponge species that are found in the region which can form large scale habitats in soft substrates. Globally, pre-drill surveys typically involve the collection and interpretation of acoustic data (BP 2019b) and/or visual data (OMV New Zealand Ltd. 2018); however, requirements often vary by jurisdiction.

To build upon existing measures, the following sections outline and provide recommendations for pre-drill surveys requirements, potentially suitable for use in the NL region. These recommendations have been summarized in Table 6. It should be noted that the list of recommendations provided in Table 6 represents the known technologies and methodologies available at the time the report was generated. However, if future advancements provide additional tools for meeting these requirements they should not be excluded from consideration.

5.1.1. Bathymetric Data

While requirements of pre-drill surveys vary throughout the world, many involve the collection of bathymetric data that are used to aid in the identification of potential coral structures (e.g. reefs), and/or areas where bottom types are suitable for such species (DNV 2013, ExxonMobil Canada Ltd. 2017). Presently, ROV mounted side scan sonar (SSS) and multibeam echosounders (MBES) are used, which allow for the efficient collection of data for the entire study area. In general, MBES generate lower resolution images with higher positional accuracy compared to SSS (Zhao et al. 2017), with the resolution of collected data dependent on the instruments distance from the seafloor (Flemming 1976, SeaBeam Instruments 2000). According to the DNV (2013) recommendations, bathymetric data are collected at a <1 m resolution. Existing project descriptions suggest that 0.5 m resolutions are typically used in the NL region (ExxonMobil Canada Ltd. 2017), but higher resolution data have also been collected. Due to their small size, many coral and sponge species and/or communities in the NL region (e.g. *Acanella arbuscula* fields) would not be observed, or identifiable, at 0.5 m resolutions (DFO 2018). In fact, because the C-NLOPB definition of coral colonies is based on the presence of large corals (>30 cm in height or width), any resolution greater than 0.3 m x 0.3 m risks missing important coral and/or sponge communities warranting visual investigation. To account for these discrepancies, a few alternative approaches have been identified. Firstly, recent technical advances have allowed for the generation of seabed images collected using SSS and MBES to be superimposed, combining the higher resolution quality of SSS with the positional accuracy of MBES data (Zhao et al. 2017). Nonetheless, the survey would still need to be completed at a ≤0.3 m resolution to improve upon existing standards and identify potential coral and sponge structures which are smaller than 30 cm. Synthetic aperture sonar (SAS) technology represents an alternative to SSS, and can produce consistent, high-resolution images (e.g. 4 cm resolution) independent of range or frequency (George and Vinodkumar 2016). Such specifications suggest it would be the most suitable tool for identifying sites potentially containing the smaller coral and sponge species that exist within the NL region. On their own, bathymetric surveys are unable to identify the species which are present within the study area. To ensure that taxonomic identification is possible, it is recommended that all proposed drill sites undergo thorough visual surveys as well.

5.1.2. Visual Surveys

Consistent with NOROG guidelines, some pre-drill visual surveys in the NL region are only conducted at sites that were identified by SSS and/or MBES to likely contain coral species (ExxonMobil Canada Ltd. 2017) (Figure 24A). More thorough visual surveys have also been performed independent of SSS and MBES surveys, through which coral and sponge communities not previously captured can be identified (BP 2019a). Existing descriptions indicate that these visual surveys extend from the proposed wellsite to a pre-defined distance (standards suggest 500 m (NS-EN 16260:2012)) along eight transects arranged at 45° intervals in a radial pattern (Figure 24B) (BP 2019a). An alternative survey design proposed by Sward et al. (2019) suggests that video data be collected in a clover-leaf pattern, extending from the proposed drill site to a predefined distance (Figure 24C). The benefit of this pattern is the increased coverage, particularly near the platform, where the release of drill cuttings and mud have the largest potential effect. Nonetheless, the use of standard transect lengths fails to consider the impact that currents could have on sediment and cutting distribution beyond 500 m. Results from dispersion models should be considered when defining the footprint of the pre-drill survey to account for the impact of currents on cutting distribution beyond a standard radius (e.g. 500 m) around the well site (Norwegian Standards 2012). A hybrid pre-drill survey approach could also be adopted, whereby the transect video survey design be supplemented by ground truthing any potential coral and sponge sites identified in the SSS and MBES data that are not located along the transect lines (Figure 24D). This type of survey would be most effective at ensuring that the maximum number of potentially important coral and/or sponge sites within the zone of influence would be identified prior to the initiation of drilling activities.

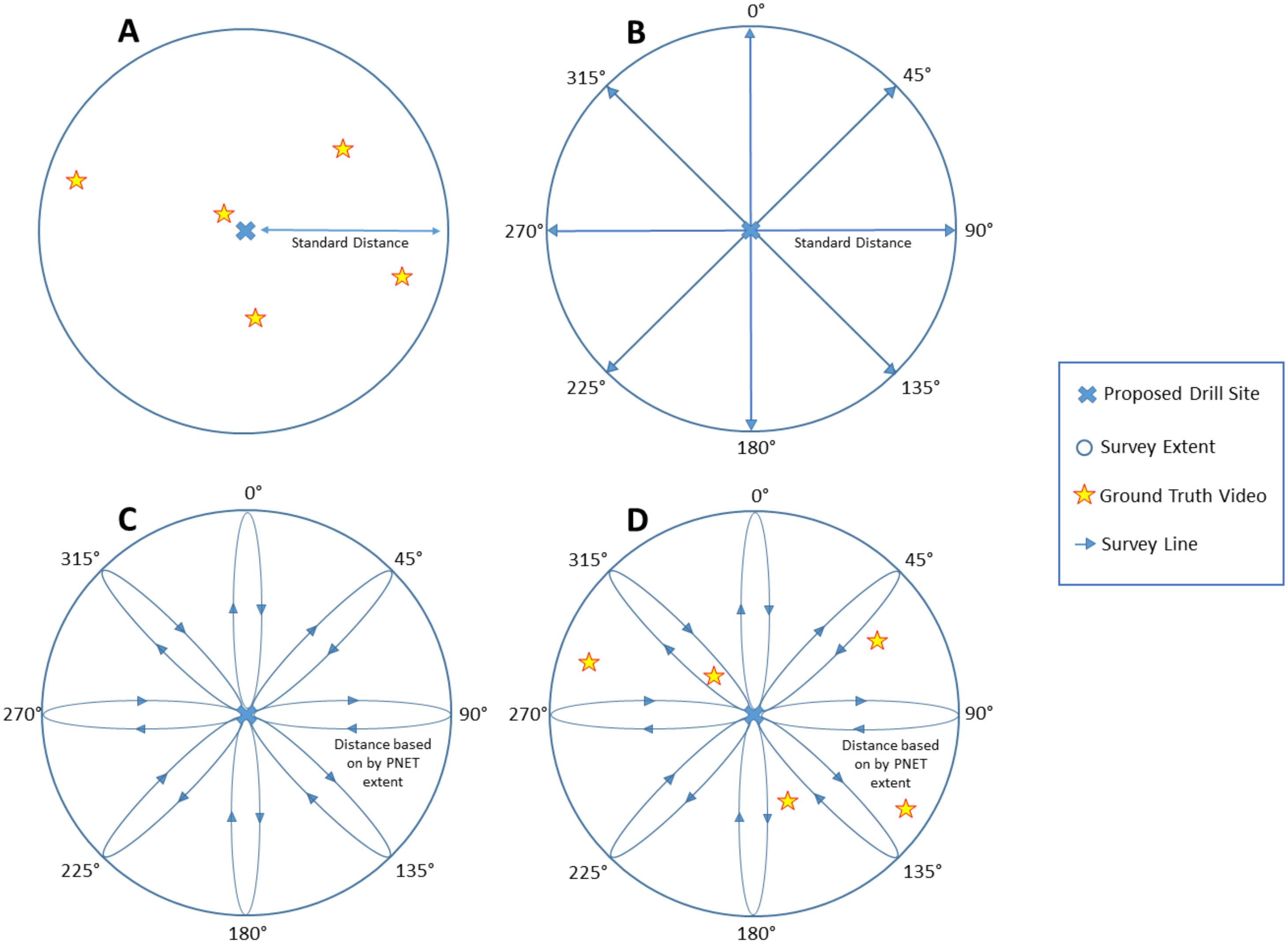

Figure 24: Pre-drill survey designs (A) Suggested NOROG visual survey of potential coral sites as observed in SSS and MBES, (B) Existing radial survey as described in existing pre-drill survey documents for the NL region, (C) Proposed clover-leaf pattern survey as illustrated in Sward et al. (2019), and (D) Proposed hybrid survey combining the clover-leaf survey pattern with additional ground-truthing of potential coral and sponge sites identified from acoustic data.

Dispersion models are used to assess how suspended sediments generated during the exploratory drilling phase will impact the area surrounding the wellsite. They provide estimates of how far sediments will disperse, as well as how the thickness of sediments changes within the dispersed area. In order to develop reliable dispersion models, sufficient baseline data should be used, as well as appropriate methodologies to predict effects. Examples of essential characteristics of these models are listed here:

1. Dispersion models should be developed using the best available current estimates. Given the complexity of the region, high spatial (order of km) and temporal (e.g. hourly) resolution of three-dimensional (3D) currents should be used. Such products are widely available in the scientific community. The Canadian Regional Ice Ocean Prediction System (RIOPS) analysis, a regional higher resolution version of the Global Ice Ocean Prediction System (GIOPS) analysis (e.g. Smith et al. 2016), is an example of such a product (that also offers short time prediction). Other alternatives are global reanalysis products that offer longer time series, such as the Global Ocean Reanalysis Simulation (GLORYS) (Parent et al. 2013) or Hybrid Coordinate Ocean Model (HYCOM) (Chassignet et al. 2009).
2. To assess seasonal and inter-annual variations of ocean currents and dispersion, stochastic predictions should be made by performing modeling ensembles covering a wide range of ocean conditions (e.g. Bourgault et al. 2014).
3. Sediment classes included in the model should be representative of the region of interest.
4. The model domain should be large enough to track the settlement of the largest possible fraction of suspended material. If a fraction of the sediment does not settle within the numerical domain, realistic hypotheses on its fate should be made and, to the extent possible, these hypotheses should be tested and validated.
5. Since sediment dispersion is sensitive to horizontal turbulent diffusivity (e.g. Bourgault et al. 2014, Matsuzaki and Fujita 2017), advective-diffusive models should use state-of-the-art turbulent closure schemes. A sensitivity analysis should also be performed on these parameters.
6. Since a plume/cloud near the bottom may be critical for benthic organisms, benthic boundary layer processes (e.g. turbulent re-settling/re-suspension mechanisms; e.g. Salim et al. 2018, Trowbridge and Lentz 2018) should be included in the model (e.g. Niu et al. 2009, Oebius et al. 2001, Gillard et al. 2019). This should include the consideration of the topography/rugosity of the area (e.g. non-flat bottoms). A sensitivity analysis of these parameters should also be performed.
7. A sensitivity analysis should be performed on all other relevant model parameters (e.g. current resolution, sediment classes if uncertain, etc.).
8. When possible, the performances of the dispersion model should be assessed using previous studies around exploratory drilling sites.

Based on dispersion modelling, proponents can identify boundary where sediment thickness may reach the probable no-effects threshold (PNET) of 6.5 mm, which is defined as the threshold above which species exhibit adverse effects as a result of burial (Kjeilen-Eilertsen et al. 2004, Smit et al. 2006, 2008). However, this threshold may not be suitable for corals and sponges because it was based on the assessment of sensitivity for 32 species of bivalves and crustaceans. More recent studies indicate that some corals are susceptible to burial at the 6.5 mm PNET or less (Larsson and Purser 2011). As information on suitable thresholds for coral and sponge species have not been well investigated at this time, a more conservative 1.5 mm threshold is often suggested for the development of pre-drill surveys to account for such discrepancies for more sensitive species (Kjeilen-Eilertsen et al. 2004). It is recommended that research be conducted to identify a PNET based specifically on the sensitivity of coral and sponge species and implement it for use in dispersion models moving forward.

At present, visual data is collected using an ROV equipped with a camera, which is flown at a consistent altitude (i.e. distance from the seafloor) to maximize the field of view and resolution (BP 2019a). Vehicle speed is a key limiting factor when performing visual surveys, as fast speeds can lead to low-quality data. As a result, the collection of high-quality video footage throughout the study area can be extremely time consuming (Yoklavich et al. 2015). Recent research has shown that autonomous underwater vehicles (AUVs) equipped with cameras may prove to be a suitable alternative to ROVs if the latter are not available, increasing the speed at which visual surveys can be performed, as AUVs are autonomous and can usually stay longer underwater (Robinson et al. 2017). However, limitations to the vehicle's altitude in low relief areas (<5 m AUV vs. 1–2 m ROV) suggest that deep-water AUVs might not provide imagery at a sufficient resolution to enable taxa identification or measurements (Wynn et al. 2014). Low flying altitudes (typically 2–3 m) are required to acquire optical images of the benthos with an AUV (Hitchin et al. 2015). Although most AUVs are intended to collect information from further above the seabed, the SeaBED AUV, developed at the Woods Hole Oceanographic Institutes (WHOI), is designed to fly just 2.5 meters above the seabed while collecting optical images of the sea floor (WHOI 2019). These technologies could provide an alternative to ROVs when completing pre-drill surveys in the NL region, provided that the survey objectives (e.g. identifying taxa, measuring specimens, estimating density) can be met. Independent of the tool used, it is recommended that all video data be collected at a maximum speed of 0.5 knots, collected along a straight line while maintaining a consistent altitude of 1–2 m from the seafloor (or as close as practically possible for an AUV). The survey platform (e.g. AUV or ROV) should be equipped with a pair of lasers for size estimation and should also have a minimum of one high definition (HD) video camera with sufficient lighting, as well as a digital still camera and a strobe light. The analysis of video data should consider quantification of abundance and density of coral and sponge taxa; therefore, planning of imagery collection should consider the need to calculate image field of view area, which might require knowledge of parameters such as vehicle altitude, speed, and camera angle throughout the survey. The platform should also be capable of collecting reference samples of species that are common, and/or dominant, and/or structure forming for positive identification.

In addition to the proposed drill site, visual surveys should also be performed for the anticipated footprint of the platform positioning system, taking into consideration any positioning uncertainty. Recent decision statements for exploration projects have indicated that where anchor and mooring systems will be used for positioning, pre-drill surveys must run at least 50 m from the extent of each anchor (CEAA 2019a, 2019b). However, it is also suggested that visual surveys should be run at a minimum of 50 m, plus the distance of positioning uncertainty, from the extent of each anchor as well as the area where the mooring line will be in contact with the seafloor (e.g. 50 m +/-15 m = 65 m). For projects where DP will be used, visual surveys should also be conducted at 50 m, plus the distance of positioning uncertainty, from the location where transponders will be deployed. This ensures that the areas under greatest threat from sedimentation and physical contact with positioning equipment are surveyed and can be relocated if corals and sponges are prevalent there.

Current guidelines indicate that once the visual survey is complete the data are reviewed to determine whether the presence of aggregations of corals or sponges, or any other sensitive features warrants the implementation of avoidance or mitigation measures. Due to the patchy nature of some coral and sponge species, it is recommended that all visual survey data collected during the pre-drill survey be reviewed, rather than only portions of the imagery, reducing the likelihood that coral and sponge species near the proposed drill-site may be missed entirely.

5.1.3. Significant Density Thresholds

The existing thresholds which define whether avoidance/mitigation measures are required for proposed exploratory drilling activities (5+ corals >30 cm in height or width per 100 m^2) rely primarily on the presence of large coral species, ignoring sponges and excluding common coral species that are smaller than 30 cm (C-NLOPB 2018). Although this threshold is used widely throughout the North Atlantic, it does not take into consideration the number of small and/or rare coral and sponge species that exist in the NL region and warrant protection, many of which are documented as VME indicator species (Fuller et al. 2008). It is also problematic for sea pens, a group of corals commonly found in soft sediments in the region, which have part of their bodies (peduncle) buried within the sediment and hidden from view. In some species, the buried peduncle can make up >45% of their total length (Baillon et al. 2015, Murillo et al. 2018). To ensure that regionally appropriate thresholds for mitigation are used, it is suggested that the life-history characteristics (e.g. morphometrics, longevity, growth rate), rarity, and VME status of the species, be taken into consideration. It is also suggested that more abundant, shorter-lived corals (e.g. soft corals) warrant different mitigation thresholds than rarer, longer-lived, VME indicator species (e.g. black corals, large gorgonians).

Work has been completed in the NL region to identify various special areas based on significant concentrations of coral and sponge species (see Section 2.6). It is recommended that exploratory drilling be prohibited within these special areas (specifically in SiBAs and VMEs) as well as in areas directly adjacent to them (e.g. within 2 km [Cordes et al. 2016]), and also areas where the densities of corals and sponges reflect those found within SiBAs and VMEs. Areas of corals and sponges have also been identified within EBSAs, so it is also recommended a precautionary approach be taken and EBSAs be avoided based on their ecological and biological significance. Because EBSAs that have coral and sponge features typically overlap with existing SiBAs or VMEs (Figure 25), it is likely that coral and sponge features within EBSAs would be protected if the recommended avoidance or mitigation measures for SiBAs and VMEs are applied.

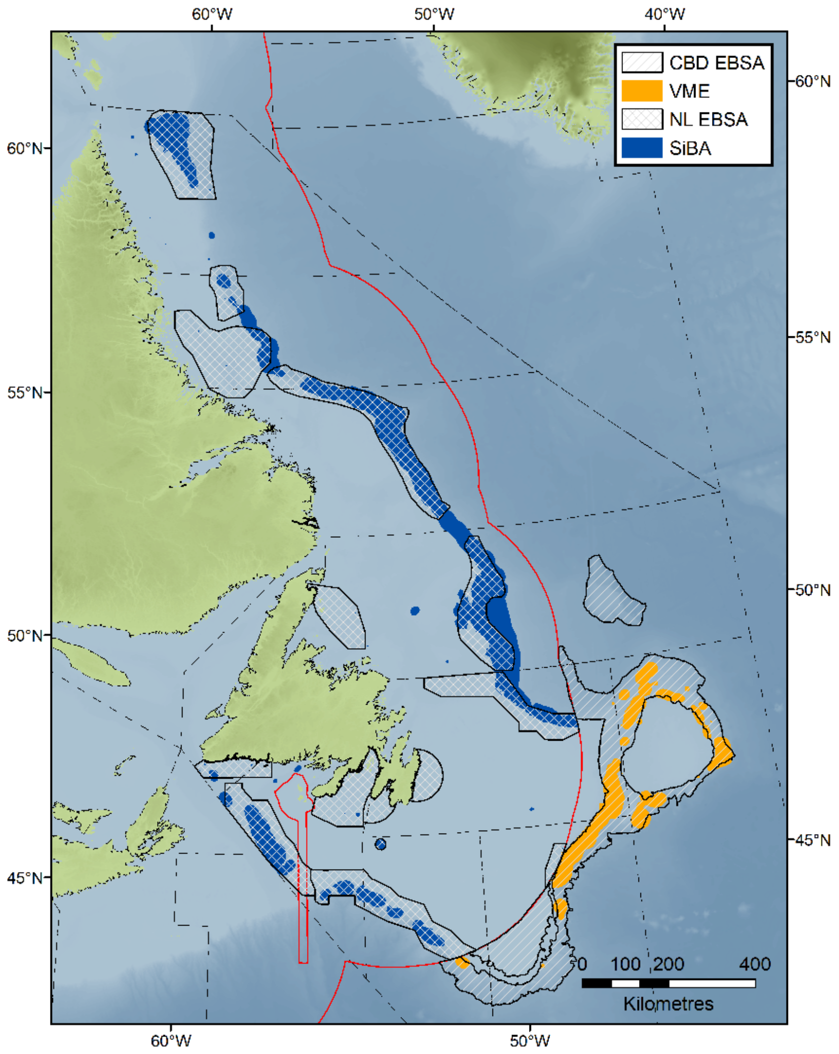

Figure 25: Overlap of EBSAs containing corals/sponges as key or other features with SiBAs (inside the EEZ) and VMEs (outside the EEZ). Note that for the purpose of this map colour has been used to distinguish between SiBAs and VMEs, but no distinction has been made to identify which species of corals/sponges they exist to protect.

Areas of significant coral and sponges concentrations in the NRA and in Canadian waters have previously been identified using kernel density estimations (KDE) applied to RV trawl survey biomass data (Kenchington et al. 2016a, 2016b, 2019). While biomass thresholds (kg/km^2) defined from KDE have been used to delineate SiBAs and VMEs (Table 4, Figure 11–Figure 13), significant density thresholds (N 100 m^{-2}) based on abundance have not yet been published for the NL region. Estimating the biomass of coral and sponge species within an area is not possible using imagery (e.g. seabed surveys). To account for this, significant density thresholds were developed for the NL region and are described below.

Owing to the unknown efficiency or selectivity of the trawl gear to collect benthic invertebrates, it is challenging to provide accurate density estimates of corals and sponges based on research trawl survey catches. In addition, some of the patches that constitute a significant concentration can be smaller than the area sampled by the gear (e.g. *Acanella arbuscula*, Table 1) and some coral groups (e.g. large gorgonians and black corals) can be found attached to isolated cobbles or boulders found in primarily muddy sand bottoms, where it is difficult to estimate *in situ* densities from trawl catches. Published biomass thresholds (NAFO 2019c) were used to calculate significant density thresholds that can be used to identify significant densities of corals and sponges within and beyond the EEZ. Until direct data from underwater imagery are collected, analyzed, and validated, the proposed significant density thresholds should be used as provisional avoidance thresholds, while acknowledging their limitations. Average individual biomass (wet weight) of each coral and sponge group used in this analysis was obtained from the 2007 EU-Spain Bottom Trawl Survey catches from within the NRA (Murillo et al. 2016b) and are indicated in Table 5. The 2007 EU-Spain Bottom Trawl Survey data were used for two main reasons. Firstly, consistent photographs of the catches were available to verify species identification done at sea, as well as the state of samples (e.g. more complete vs. fragments only). Secondly, in those surveys sponges were identified at low taxonomic levels (e.g. species), allowing for their categorization into size classes (e.g. small vs. large sponges). As previously mentioned, sponges are currently not identified at low taxonomic levels at sea during DFO-NL RV surveys.

Although gear efficiency for sampling corals and sponges in the NRA and Canadian waters is currently unknown, preliminary studies have estimated that efficiencies range between 0.3 and 1.9% for sponges sampled with Campelen and Lofoten gears, and it is around 5.2% for sea pens sampled with Campelen gear (Kenchington et al. 2011). As such, for the purpose of this report, thresholds were calculated for VMEs and SiBAs in the NRA and Canadian waters, respectively, at two gear efficiencies: 1% and 5%.

Using the available information on threshold biomass (NAFO 2019c), average individual biomass per coral and sponge group, and gear swept area and potential efficiency, we calculated density thresholds (Table 4). For instance, for these surveys large sponge average biomass was 2.5 kg/individual (Table 5); based on the sponge VME biomass threshold of 100 kg, this corresponds to an abundance of 40 sponges (Table 4). If gear efficiency were at 100%, this would signify a threshold density of 0.1 sponges/100 m^2, while a gear efficiency of 1% would mean a density threshold of 10 sponges/100 m^2 (Table 4).

Assuming gear efficiencies of 1% for sponges, the number of large sponges expected in 100 m^2 of SiBA (within the Canadian EEZ) and VME (within the NRA) grounds would be between 10 and 6, respectively (Table 4). While for sea pens, assuming a gear efficiency of 5%, the number of individuals per 100 m^2 would be between 10 and 4 for Canada (SiBAs) and the NRA (VMEs), respectively (Table 4). Although no gear efficiency estimate is available for small gorgonians, the predominant species in the area (*Acanella arbuscula*) lives on soft bottoms, and it is found in similar areas than sea pens. Therefore, a 5% gear efficiency was also considered for these taxa, resulting in 1-2 small gorgonians per 100 m^2 (Table 4). Similarly, for black corals and large gorgonians, although no gear efficiency estimates are available, the number of individuals for 100 m^2 would be 1 for the lowest gear efficiency (1%) in both areas, and <1 for higher gear efficiencies (Table 4).

Although we show density thresholds based on various gear efficiencies (Table 4), using a precautionary approach and selecting the lower density value between both areas (Canada and NRA), the coral and sponge density thresholds per 100 m^2 is 6 organisms for large sponges (>5 cm), 4 for sea pens, and 1 for small and large gorgonians and black corals (Table 4).

Due to the lack of published biomass thresholds for significant concentrations of other non-VME “common” coral species (e.g. soft corals, stony cup corals) no density thresholds are provided for these groups, but this may change in light of new science. Similarly, no threshold was provided for other non-VME “rare” species such as hydrocorals, but DFO Science is interested in observations, specimens, and data related to these rare species.

Table 4: Coral and sponge thresholds used to define VME and SiBA biomass thresholds in the NAFO Regulatory Area (NRA) and in Canadian waters, respectively. The swept area of Lofoten and Campelen gear, as well as estimated density thresholds (N.100 m^{-2}) based on different gear efficiencies are also indicated. ***Recommended significant density thresholds proposed in this study are in bold.***

				Density Thresholds (N. 100m^{-2}) based on various Gear Efficiencies			
NRA	**VME biomass threshold (kg)**	**Abundance threshold (N)**	**Swept area Lofoten[1] (m^2)**	**100%**	**10%**	**5%**	**1%**
Sea pens	1.3	81	39,000	<1	2	**4**	21
Large gorgonians	0.6	2	39,000	<1	<1	<1	**1**
Small gorgonians	0.2	20	39,000	<1	<1	**1**	5
Black corals	0.4	4	39,000	<1	<1	<1	**1**
Large sponges (>5 cm)	100	40	39,000	<1	1	2	10
Canada	**SiBA biomass threshold (kg)**	**Abundance threshold (N)**	**Swept area Campelen[2] (m^2)**	**100%**	**10%**	**5%**	**1%**
Sea pens	2	125	24,935	1	5	10	50
Large gorgonians	1	3	24,935	<1	<1	<1	**1**
Small gorgonians	0.2	20	24,935	<1	1	2	8
Large sponges (>5 cm)	40	16	24,935	<1	<1	1	**6**

[1]*Murillo et al. (2016);* [2]*Stansbury et al. (1998)*

Table 5: Mean (+SD) individual biomass (wet weight) per coral group and sponge caught during the 2007 EU-Spain Bottom Trawl Survey. N1: number of trawl sets included in the analysis; N2: number of organisms (only records with complete organisms were considered). The species used in the calculations are also indicated.

	N_1	N_2	Mean±SD (kg)*	Species
Sea pens	117	3,875	0.016±0.034	*Anthoptilum grandiflorum* (54%), *Pennatula aculeata* (22%), *Funiculina quadrangularis* (12%), *Halipteris finmarchica* (5%), *Halipteris* cf. *christii* (3%), *Umbellula lindahli* (3%), *Kophobelemnon stelliferum* (1%), *Pennatula grandis* (1%), *Distichoptilum gracile* (<1%), *Protoptilum carpenteri* (<1%), *Virgularia* cf. *mirabilis* (<1%)
Large gorgonians	21	30	0.4±0.8	*Acanthogorgia armata*, *Paragorgia* spp., *Paramuricea* spp.
Small gorgonians	15	46	0.01±0.01	*Acanella arbuscula*
Black corals	10	25	0.10±0.08	*Stauropathes arctica*
Large sponges (>5 cm)	26	514	2.5±1.5	*Geodia* spp., *Stelletta normani*, *Stryphnus fortis*

These provisional significant density thresholds were calculated in the abscence of published thresholds that could be used to identify significant concentrations of corals and sponges in the NL region from imagery data (i.e. pre-drilling seabed surveys). While previous thresholds used by the oil and gas industry seem to have been partially adopted from guidelines outlined in DNV 2013 based on *Lophelia pertusa* reefs, gorgonian corals, and coral gardens, there is no public information on how those values were calculated (e.g. 5+ large corals per 100 m^2). In this sense, the density thresholds presented here have the advantage of being based on regional data (including commonly local taxa), and VME and SiBA biomass thresholds already used by NAFO and Canada, respectively. Nonetheless, we caution that: 1) the gear efficiencies applied here did not account for the inherent variability associated with the patchy distribution of corals and sponges and other issues mentioned previously, in addition to external factors that could also influence both gear efficiency and selectivity; 2) abundance estimates from trawl gear in this region have not yet been compared to estimates from imagery data, and these are expected to differ (e.g. Chimienti et al. 2018) and might need calibration; 3) the relationship between biomass and abundance is less clear for large gorgonians, as samples are often fragmented when brought back aboard (although only samples considered complete were included in the 2007 EU-Spain Bottom Trawl Survey); 4) the inclusion of Canadian RV survey as well as EU-Spain Bottom Trawl Survey data from additional sampling years might generate different density thresholds than those provided here. Depending on the proportion of different species in a catch, total biomass can vary, as different taxa within a same group can be different in their sizes and weights. Therefore, these thresholds should be considered preliminary and reviewed as detailed *in situ* imagery data from the special areas (VMEs and SiBAs) are collected.

Table 6: Pros and Cons of proposed technologies, methodologies, and thresholds for pre-drill surveys at proposed drilling sites.

Category	**Method**	**Pros**	**Cons**	**Use?**
Technology	SSS (<1 m resolution) (DNV 2013)	- Efficiently able to capture large amounts of data from a large area - Capable of acquiring higher-resolution images of seafloor compared to MBES - Minimally invasive	- Suggested 0.5 m resolution (Husky Energy 2018) is unable to pick up many of coral and sponge species that exist in the NL region - Would not provide information on height of “anomalies” (e.g. corals) that are detected - Cannot be used for species level identification of corals and sponges that are observed - Low positional accuracy of data if mounted on towed camera systems	Currently Used
Technology	MBES (<1 m resolution) (DNV 2013)	- Efficiently able to capture large amounts of data from a large area - High positional accuracy of data - Minimally invasive	- Suggested 0.5 m resolution (Husky Energy 2018) does not allow detection of many of coral and sponge species that exist in the NL region - Generally produce lower resolution images compared to SSS - Cannot be used for species level identification of corals and sponges that are observed	Currently Used
Technology	Superimpose SSS on MBES (Zhao et al. 2017)	- Combines the positional accuracy of MBES with the high-resolution imagery of SSS - Minimally invasive	- Cannot provide species level identification - Depending on the resolution it still may not be able to detect many of coral and sponge species that exist in the NL region - Complex analyses required to combine these datasets	Potential Alternative
Technology	Synthetic Aperture Sonar (SAS) (George and Vinodkumar 2016)	- Higher resolution than typical SSS which would be capable of identifying areas	- Maximizing resolution requires reduced platform speed, meaning that data collection would be slower in comparison to SSS and MBES	Potential Alternative

Category	Method	Pros	Cons	Use?
		with coral and sponge assemblages in the NL region - Resolution is independent of range and frequency - Minimally invasive	- Unable to provide species level identification	
Technology	Dispersion Modelling (DNV 2013)	- Cost effective and efficient way to provide information on sediment dispersion under various scenarios - Minimally invasive	- Real scenario will likely be different to some degree - Requires accurate validation data (e.g. strength of currents, sediment composition, etc.), which can be challenging to obtain - Testing multiple scenarios (varying seasonal and inter-annual conditions, sensitivity on different parameters, etc.) is a lengthy task	Currently Used
Technology	Video Collection using ROV (Yoklavich 2015)	- Able to provide high quality images of coral and sponge species for identification and measurement - Real-time seafloor view allows for changes on the fly to investigate corals and other organisms near transect lines (Sward et al. 2019)	- Takes much longer to collect quality video data compared to SSS and MBES data, because footprint of video is small and needs to be recorded at slow speeds for taxa identification (0.25–0.5 knots) - Considerations associated with installation and deployment from vessels. However, ROVs are already commonly used in oil and gas platforms for inspection and maintenance - Typically only used throughout a small portion of the study area, missing potentially important coral and sponge areas	Currently Used

Category	Method	Pros	Cons	Use?
		- Particularly useful in areas with rugged terrain - Can be used for species identification (depends on video quality and resolution) - Many ROVs can collect specimens - Minimally invasive		
Technology	Video Collection using AUV (Yoklavich 2015, Robinson et al. 2017)	- Easy to operate - Runs autonomously along pre-programmed track - More efficient video collection than ROV	- Unable to change path on-the-fly to investigate areas/specimens of interest (no real-time view) - Unable to sample specimens - Difficulties for taxonomic identification of species or even groups if unable to fly close to seafloor - Video needs to be recorded at slow speeds for taxa identification (0.25–0.5 knots) - Less effective in rugged terrain - Limited by high currents - Relies on battery life	Potential Alternative
Technology	Video Collection: Towed Camera (Williams et al. 2015; Yoklavich 2015)	- Least expensive - Easy to operate	- Less maneuverable than ROV - Potential to impact seafloor due to cumbersome nature (e.g. height controlled by adjusting length of tow cable) - Difficulties for taxonomic identification of species or even groups - No thruster power makes it less suitable for high current areas	Potential Alternative

Category	**Method**	**Pros**	**Cons**	**Use?**
Methodology	Video Collection: Ground Truth Sites Only (DNV 2013)	- Efficient species identification of areas most likely to contain coral/sponge assemblages - Less time spent surveying areas that may not have any corals or sponges	- Relies on the SSS and MBES data whose resolution is too low for corals and sponges in the NL region - May miss important coral and sponge areas due to their patchy nature	Currently Used
Methodology	Video Collection: Radial Pattern (BP 2019a, Sward et al. 2019)	- Provides coverage independent of SSS and MBES observation in a standardized, reproducible mannerg - Visual data is collected over a larger area than when only ground-truthing is done	- Because of the survey pattern, large areas of the seafloor are not investigated for coral and sponge presence/absence	Currently Used
Methodology	Video Collection: Cloverleaf Pattern (Sward et al. 2019)	- Covers a larger footprint than radial and ground truth surveys - Increased coverage closer to the drill-site where impact is most significant	- More time consuming to complete than other visual surveys listed	Potential Alternative
Methodology	Video Collection: Hybrid Survey (Cloverleaf Pattern	- Covers a larger footprint than radial	- More time consuming to complete than other visual surveys listed	Recommended Alternative

Category	Method	Pros	Cons	Use?
	(Sward et al. 2019) & Investigation of Potential Coral and Sponge Sites Identified from Acoustic Data	and ground truth surveys - Increased coverage closer to the drill-site where impact is most significant - Reduces the likelihood that coral and sponge sites are missed by also investigating potential sites from bathymetry		
Thresholds	Effects Threshold of 6.5 mm (Smit et al. 2006, 2008)	- Scientifically sound threshold to determine how far a pre-drill survey should extend from a proposed well site and is supported by literature	- The threshold is based on a study which considered the sensitivity of 32 marine species (crustaceans and bivalves), none of which were coral or sponge species, to burial by drill cuttings - These species were tested under laboratory conditions - The threshold was based arbitrarily on the drill cutting thickness where 5% of the species will be potentially affected - No considerations for different types of drilling muds	Currently Used
Thresholds	Effects Threshold of 1.5 mm (Kjeilen-Eilertsen et al. 2004, CEAA 2019a)	- A more cautious threshold applied in study areas known to contain more sensitive species - In the lack of other information, a more	- Arbitrary threshold assigned to account for “more sensitive species”	Currently Used

Category	Method	Pros	Cons	Use?
		cautious approach is warranted		
Threshold	Survey Threshold from Anchors: 50 m (DNV 2013)	- Survey extends the full distance of the potential influence area described by DNV (2013)	- Does not consider the pre-lay inaccuracy of +/-15 m - Does not consider the areas where mooring lines meet the seafloor	Currently Used
Threshold	Survey Threshold from Anchors: 65 m	- Survey extends the full distance of the potential area plus positioning uncertainty described in DNV (2013)	- Does not consider the areas where mooring lines meet the seafloor	Potential Alternative
Threshold	Survey Threshold from Anchors & Mooring Lines: 65 m	- This considers the full corridor of impact for the anchor and mooring lines as well as the positioning uncertainty described in DNV (2013)	- Uncertainty exists about the true extent of impact associated with anchor and mooring operations	Recommended Alternative
Threshold	Avoidance Threshold: Avoid all special areas	- Special areas are already defined as significant for coral and sponges - Disturbances in these areas are likely to have a significant and long-lasting impact - They will be updated and	- They only consider the areas with the highest coral and sponge density - May miss areas where data could not be collected by the trawl gear	Potential Alternative

Category	Method	Pros	Cons	Use?
		revised based on new information - Specific to the NL region		
Threshold	Avoidance Threshold: Outside SiBAs and VMEs avoidance defined based on observation of corals and/or sponges at or above provisional density thresholds and within 2 km buffered boundary: **VME indicator Species Avoidance Thresholds:** *Large Sponges* = 6+ organisms within 100 m^2 *Sea Pens* = 4+ organisms within 100 m^2 *Small Gorgonians, Large Gorgonians, and Black Corals* = 1+ organisms within 100 m^2	- Thresholds calculated based on regional data - Puts greater protection on VME indicator species - Can be updated as new information becomes available	- Ignores individual species in favor of broad group distributions - Ignores non-VME species - Trawl data densities and video-based densities may differ.	Recommended Alternative

Category	Method	Pros	Cons	Use?
	Non-VME indicator species Avoidance Thresholds: No threshold but adjust/incorporate according to new science.			
Threshold	Avoidance Threshold: Avoidance mandatory inside all SiBAs and VMEs & within 2 km buffered boundaries	- Put emphasis on special areas whose boundaries are defined based on high densities of coral and sponge species - Boundaries already exist and make an easily identifiable area to apply avoidance measures. - Applies a buffer to account for the potential distribution of muds and cuttings from drills sites outside the SiBA and VME boundaries	- Unable to account for the areas beyond the SiBAs and VMEs that contain comparable densities of coral and sponge species. - These areas are defined based on VME indicator species; thus, they ignore the various other species which exist throughout the region.	Recommended Alternative
Threshold	Mitigation Threshold: *Lophelia pertusa* reef or 5+ large corals (>30 cm) within 100 m^2	- Commonly used guideline for mitigation used throughout the North Atlantic	- Thresholds were based on species concentrations and abundances in Norwegian waters, and are not entirely relevant in the NL region	Currently Used

Category	Method	Pros	Cons	Use?
	(ExxonMobil Canada Ltd. 2017, Statoil Canada Ltd. 2017, C-NLOPB 2018)		- Thresholds do not consider the presence of sponge species and how that would trigger mitigation - Does not consider VME status - Does not consider rarity of certain species (e.g. black corals) - Seemingly arbitrary threshold value	
Threshold	Mitigation Threshold: 5+ corals within 100 m^2 (no size dependency)	- Similar to pre-existing guideline - Blanket threshold for all species/functional groups - More suitable for the NL region	- Does not consider VME status - Does not consider rarity of certain species (e.g. black corals) - Seemingly arbitrary threshold value	Potential Alternative
Threshold	Mitigation Threshold: Mitigation Threshold set based on Group & VME Status **VME indicator Species Thresholds:** *Presence:* - Black Corals *5+ colonies/individuals within 100 m^2* - Sponges - Large Gorgonians	- More suitable for the NL region - Puts greater protection on VME indicator species	- Ignores individual species in favor of broad group distributions - Ignores non-VME species - Seemingly arbitrary threshold value	Potential Alternative

Category	Method	Pros	Cons	Use?
	- Small Gorgonians - Sea Pens **Non-VME indicator species Thresholds:** No threshold but adjust/incorporate according to new science.			
Threshold	Mitigation Threshold: Mitigation requirement determined based on VME status **VME Indicator Species Thresholds:** Presence below avoidance thresholds **Non-VME indicator species Thresholds:** No threshold but adjust/incorporate according to new science.	- Based on available science - More specific to the NL region - Puts greater protection on VME indicator species even when found in low numbers - Can be updated as new information becomes available	- Ignores individual species in favor of broad group distributions - Ignores non-VME species - In some cases the simple presence of a coral or sponge VME indicator species would warranty mitigation	Recommended Alternative

5.2. EXPLORATORY DRILLING ACTIVITIES

Depending on the results of the pre-drill survey, recommendations are made by FFHPP to avoid and/or mitigate the potential impacts that exploratory drilling will have. Recommendations for avoidance and mitigation techniques that are potentially suitable for use in the NL region are presented in Table 7 and Table 8. It is important to note that for the purpose of this report the suitability of a mitigation measure was defined based on its history of successful application, and its ability to withstand poor weather conditions. It did not take into consideration the geological characteristics of the area, which may limit the application of some mitigation measures to a site-by-site evaluation, or the human health and safety risks that could be associated with them.

5.2.1. Positioning

If anchors are used for positioning the drilling platform, cold-water corals and sponges near the site would be at risk of physical damage, subsequent side effects of damage (e.g. parasitic hydroid colonization), and possible mortality as a result of contact with the anchors and associated chains, pennants, and wires which connect them to the platform. Increased rates of sedimentation during deployment of the anchoring equipment could also put the species at risk of smothering or burial. The severity of these impacts would vary depending on the anchor and mooring systems that are used, as well as the method of deployment, but they correlate positively with the spatial coverage, or footprint, of the equipment. In general, remotely operated vehicles (ROVs) can be used to reduce the impacts that anchor handling operations have on the benthic environment by assisting with deployment and retrieval (DNV 2013). The most suitable option would be to deploy the anchors using ROVs, as this would minimize the effect that installation operations would have on the benthic environment. This could be done for standard anchor installations, for anchor chains with buoyancy added, or anchors and chains with larger diameters. Of these options, both buoyant anchor chains as well as the heavier anchors and chains would reduce the footprint and the horizontal movement of the anchor chains when compared to standard anchor installations (DNV 2013).

Although it is associated with increased emissions by the drilling platform, using a DP system is the best option for mitigating the impacts that anchoring operations have on corals and sponges (DNV 2013, CEAA 2019a). This technology is commonly used in the NL region and has an extensive track record of success (NSB Energy Consulting 2016). Although the deployment of various transducers on the seafloor is required for this method, the footprint of their impact would be quite small compared to standard anchoring operations.

5.2.2. Drilling

Other recommendations for mitigation have been outlined for the drilling phase, which aim to reduce the volume of drill cuttings that are generated during oil and gas exploration. Conductor Anchor Nodes (CAN) are often suggested as they eliminate the need for drilling the first section of the top hole, require no cementing, increase the stability of the well, and can be installed more quickly (DNV 2013). However, their application is limited by the soil formation characteristics on site, and the riserless drilling of the second, 26” section of the top hole is still required. Alternatively, a slim hole well design can be used whereby smaller diameters are drilled of each well section. Although this reduces the volume of cuttings generated, there is limited flexibility for dealing with drilling problems in the well, there are restrictions on the maximum completion size, and the drill strings used are considered mechanically weaker. To overcome these issues, alternative recommendations suggest replacing a wider section of the well with a longer, thinner section (e.g. longer 17.5” section in place of a 26” and 17.5” section)

(DNV 2013). Again, reducing the diameter of the well limits flexibility for dealing with drilling problems if they arise. One major problem with each of these mitigation measures, is that they do not eliminate the risk of increased sedimentation, instead acting to reduce it. As such, additional mitigation measures would be required to account for the generation of the remaining drill cuttings.

Top hole drilling, which occurs before the marine riser is installed, represents the drilling operation that has the largest potential impact on coral and sponge species. As such, methods which reduce or eliminate the release of drill cuttings and mud directly on the seafloor are important to consider. Due to historical success, the use CTSs, which relocate drill cuttings to areas where impacts would be less significant, is commonly recommended for mitigation the risk of drill cuttings (ExxonMobil Canada Ltd. 2017). Although the theoretical range of CTSs is 3,000 m, their suggested use would be restricted to areas where sediments can be safely deposited at locations up to 1,000 m away, as experience with ranges >1,000 m is limited. This technology may also be susceptible to blockages in the line, a failure which could lead to the disposal of cuttings at the drilling site (DNV 2013). It is also dependent on the availability of a site where concentrations of coral and sponge species do not meet avoidance/mitigation thresholds, which may be more difficult to identify in or near pre-defined special areas of high coral or sponge concentrations such as VME habitats, SiBAs, EBSAs, MPAs and MRs. The identification of proper disposal sites would also require an independent pre-drill visual survey to ensure coral and sponge species were not present at or above density thresholds there or along the route where equipment would be installed. A more conservative approach to cuttings disposal is to use Riserless Mud Recovery systems (RMR), which capture drill cuttings and mud released during top hole drilling and transfers them to the drilling platform for processing. Unlike the standard top hole drilling procedures, this eliminates the disposal of the cuttings directly at the drill site and allows for the mud to be recovered and reused in the drilling operation. However, as seen with the CTS, failure of these systems could also result in the discharge of cuttings and mud at the well site (DNV 2013).

There are numerous options for the disposal of drill cuttings if a RMR system is used. One recommendation by DNV (2013) is that the treated cuttings are released at the sea surface. This option typically causes cuttings to settle more thinly on the sea floor as a result of their dilution in the water column and distribution by currents. It is suggested that this would minimize the impact that sediments would have on corals and sponges, compared to bulk release at the well site, but this may also increase the footprint of the impact. Because it is more difficult to predict where the sediments will settle when they are released at the sea surface, the impacts may also be more severe than if other mitigation measures were used. In some instances, slurry units are used to grind the cuttings into smaller particles before they are released into the water column (DNV 2013). This technique allows the cuttings to spread over even larger areas, as they stay suspended in the water for longer, but it does not take into consideration that in some cases finer particles are more difficult for coral and sponge species to clean off (Weber et al. 2006, Schönberg 2016). The slurrified cuttings may also be transported via CTS from the platform to another location, although there is limited experience with the combination of these two technologies. Other research suggests the possibility of mixing water and chemicals with the slurrified cuttings to create “spud mud”, which can then be used to drill the next section of the well; however, at present no commercially available technology is in production (Taghiyev et al. 2015). Other options include the reinjection of slurrified drill cuttings into either a disposal well, or the annular space between the conductor pipes and well wall (OGP 2003). Although both these methods eliminate the disposal of sediment on the seafloor, they are more complex, and require specific geological formations to properly contain the disposed cuttings. Additionally, transport into a disposal well suggests a second well would have to be drilled, while annular reinjection risks damaging the existing exploration well. The use of these methods in the NL region may also be restricted as they have not been thoroughly tested on floating drilling platforms, or in deep water (OGP 2003).

More conservative approaches, which are already required for projects where OBMs are used, involve the transfer of treated drill cuttings to a supply vessel for bulk transport and disposal onshore. The transfer can be completed using either a crane or transfer lines which may or may not be pressurized (DNV 2013). However, because crane operations are particularly sensitive to weather conditions, transfer lines may not be recommended for the NL region. One of the major drawbacks of these methods is the additional carbon emissions associated with requiring a dedicated supply vessel.

5.2.3. Abandonment

One of the primary concerns during the abandonment phase is related to the redistribution of drill cuttings and mud which had been deposited at the well site during exploration. If mitigation measures are implemented during the initial stages to prevent the buildup of this material (e.g. top hole drilling), remaining concerns would be limited to the distribution of natural sediments and potential for physical contact with anchors during retrieval. The primary mitigation measure recommended for this stage is ROV assisted retrieval of the anchors and chains (DNV 2013). This method eliminates the need for grappling, thus minimizing the impacts to coral and sponge species. This is a commonly used method for anchor retrieval, particularly in areas known to support sensitive habitats.

In general, many of the mitigation techniques described above rely partly or entirely on suitable weather during installation, and/or standard operations. Because of the harsh weather conditions in the Northwest Atlantic, these forms of mitigation have the potential to reduce the efficiency of drilling operations. Depending on the time of year when drilling is scheduled to take place, one of the biggest considerations that should be made when outlining mitigation options is how tolerant a technique is to poor weather. In addition, techniques that have not been thoroughly tested (e.g. spud mud), particularly in deep waters (e.g. cuttings reinjection), should be restricted to drill sites where conditions resemble those where they have been successfully implemented in the past. If these methods are to be used under different conditions, a suitable backup for mitigation should also be prepared.

Table 7: Potential avoidance measures to employ in areas with aggregations of corals and sponges

Exploration Phase	**Avoidance Measure**	**Description**	**Pros**	**Cons**	**Suitable in NL?**
Site Identification	Relocate Drilling Site (CEAA 2019a)	Identify a secondary drilling site that will not impact coral and sponge species.	- Eliminates the risk to coral and sponge concentrations - Does not require the use of additionally costly mitigation measures	- A secondary site may not be readily available	Yes
Positioning	Use Dynamic Position (DP) (DNV 2013)	In place of anchor and mooring lines to maintain the position of the drilling platform; deploys transponders at locations without coral and sponges and use this to position the platform.	- Eliminates the risks associated with anchor deployment and recovery operations - Eliminates the requirement for mooring lines	- Limited use in shallow-water depths - Increased fuel consumption - Increased cost to use DP - Transponders could still have impact on localized areas of habitat	Yes

Table 8: Potential mitigation measures to employ in areas with aggregations of corals and sponges

Exploration Phase	**Mitigation Measure**	**Description**	**Pros**	**Cons**	**Suitable in NL?**
Positioning	Pre-lay anchors and chains (DNV 2013)	Pre-laying anchors and chains allows for increased accuracy in their position, enabling operators to better mitigate their impact on coral and sponges in the study area.	- Reduces risk to corals and sponges - Pre-lay activities can be monitored and assisted by an ROV	- Adds a separate marine operation onto the agenda - Can increase operational costs - AHV with ROV is required	Yes
Positioning	Add buoyancy to anchor chains (DNV 2013)	Portions of the anchor chains can be replaced with more buoyant fiber wire and buoys can be added to reduce the impact that anchor chains have on coral and sponge species.	- Reduced risk of mechanical damage to corals and sponges - Mooring footprint is reduced, as point of touchdown is extended further from drill site - Reductions in horizontal movement of anchor chains, which decreases with distance from drill site	- Increased cost - More complex - More time required to complete operations - Increased chance that operations will be impacted by weather	Yes
Positioning	Use heavier anchors and chains (DNV 2013)	By increasing the size/dimensions of anchors and chains it is possible to reduce the length of the chain required for mooring.	- Decreased footprint of anchor and chains - Reduced risk of mechanical damage to coral and sponge species	- Increased cost	Yes

Exploration Phase	Mitigation Measure	Description	Pros	Cons	Suitable in NL?
			- Increased flexibility for anchor placement		
Drilling	Use of a Conductor Anchor Node (CAN) (DNV 2013)	The first section of the well (36”) is installed as part of a CAN, which is put in place using piling rather than drilling.	- Requires a shorter conductor - Reduced discharge of cuttings - Reduced impacts to coral and sponge species during the riserless drilling phase - Quicker installation than the conventional conductor - No cementing required for this section	- Limited by soil or formation characteristics - Drilling of the 26” top hole section of the well is still required - High risk of failure with piling of conductor	Maybe (site-dependent)
Drilling	Slim hole well design (DNV 2013)	In this design smaller diameters are used when drilling the well sections.	- Reductions in discharged drill cuttings - Reduced distribution of particles - Reduced impact on coral and sponge species	- Limited flexibility in mitigating against drilling problems in well - Restrictions in maximum possible completion size - Drill strings are mechanically weaker	Yes
Drilling	Reduction in number of sections (e.g. 26” removed) (DNV 2013)	By replacing one section of the well with an extended section of a smaller diameter (e.g. longer 17.5” section instead	- Reductions in discharged drill cuttings - Reduced distribution of particles	- Limited flexibility in mitigating against drilling problems in well - Limited by specific formation characteristics - Increased use and discharge of drilling fluids with special	Maybe (site-dependent)

Exploration Phase	Mitigation Measure	Description	Pros	Cons	Suitable in NL?
		of 26" and 17.5") the amount of material discharged from the well is reduced.	- Reduced impact on coral and sponge species	specifications for smaller well sections	
Cuttings Disposal	Cutting Transport System (CTS) (DNV 2013)	In areas where coral and sponge species are found, the CTS can be used to capture drilling fluid and cuttings from the wellhead and transport them to another location.	- Widely used technology that is considered standard practice - Increases the flexibility for positioning of the drill site - Typical range or transport is 500 m, but theoretical range is 3,000 m - Provides good prediction and control of particle distribution.	- Operation requires good communication with the driller and awareness and experience by the operator - Potential for blockages to occur - In the event of failure, discharge will occur at the drill site - There is limited experience with transport of cuttings over 1,000 m - Installation cost are high - For extended ranges (+250 m) ROV access is recommended	Yes
Cuttings Disposal	Riserless Mud Recovery systems (RMR) (DNV 2013)	Cuttings and fluids are captured at the drill site during top hole drilling and returned to the drilling platform for the separation and recovery of drilling fluids for reuse. Cuttings are discharged at the sea surface.	- Reduced risk of cuttings sedimentation near the drill site during top hole drilling - Allows for the reuse of drill fluids - Enables drilling of top hole with weighted mud	- Operation requires good communication with the driller and awareness and experience by the operator - In the event of failure, discharge will occur at the drill site - Risk for reductions in progress of drilling operations - Weighted and viscous system needed to lift cuttings - Requires additional work to handle and dispose of drill cuttings on platform	Yes

Exploration Phase	Mitigation Measure	Description	Pros	Cons	Suitable in NL?
				- More expensive than CTS - Installation and recovery vessels required, with operation susceptible to weather conditions	
Cuttings Disposal	Discharge of water-based cuttings from drilling platform (DNV 2013)	Water-based drill cuttings are passed through a shaker where they are separated from drilling muds. These cuttings are then released at the sea surface.	- Sediments are diluted, reducing exposure to corals and sponges - This is the typical method used for discharging water-based cuttings on drilling platforms - Cost effective - Can be interfaced with RMR system with minimal modifications	- Operators have less control of where cuttings will end up - Possible that the impact on coral and sponges could be more significant than when discharge occurs at a specific location (e.g. by CTS) - Requires additional equipment for use during top hole drilling (e.g. RMR system)	Yes
Cuttings Disposal	Coarse slurrification and discharge from platform (DNV 2013)	Drill cuttings are brought to the platform and processed through a slurry unit which grinds the cuttings into finer particles. The particles are then mixed with water and discharged to sea.	- Reduce the risk of cuttings sedimentation at the drill site	- Increased risk of halting operations if slurry unit malfunctions - Slows drilling progress, acts as bottleneck in waste management - Requires additional equipment - Increases costs	Yes
Cuttings Disposal	Coarse slurrification of cuttings and disposal at the	Cuttings are transported to the platform for slurrification and	- Many crane operations are eliminated	- Limited experience with this technology - Increased operational risk due to uncertainty of success	Maybe (limited experience)

Exploration Phase	Mitigation Measure	Description	Pros	Cons	Suitable in NL?
	sea floor (DNV 2013)	then transported by a CTS to a more optimal deposit site on the seafloor.	- Suitable for all sections of the well (including top hole) - Slurrification of cuttings reduces risk of obstructions in CTS - Lower overall environmental impact when supply vessel not required	- May require a supply vessel to transport cuttings onshore as a contingency - Reduced progress during top hole drilling - Requires specialized equipment and space - More complex than other scenarios - Likely more costly than other scenarios	
Cuttings Disposal	Slurrification and reuse as spud mud (DNV 2013)	Drill cuttings are processed by a slurry unit in which they are ground into finer particles, mixed with water and chemicals, and then reused in the next section of the well.	- Reduce the risk of cuttings sedimentation at the drill site - Reduces the generation of cuttings and use of drilling fluid equal to the volume of just one well section	- Increased risk of halting operations if slurry unit malfunctions - Slows drilling progress, acts as bottleneck in waste management - Requires additional equipment - Increases costs - Generated cuttings and drilling fluid limited to one section if reused on the same drilling platform - No existing system available to industry - Increased use of chemicals during treatment	No (no existing system available)
Cuttings Disposal	Annular reinjection of drill cuttings (OGP 2003)	Drill cuttings are processed into a slurry and reinjected into the annulus space of the well for disposal.	- Eliminates need for supply vessel to bring waste onshore - Does not require a disposal well - Eliminates impact of sedimentation from	- Risk of damaging exploration well - Requires thorough analysis to evaluate suitability of site - Requires additional equipment that will take up space on drilling platform	Maybe (limited experience)

Exploration Phase	Mitigation Measure	Description	Pros	Cons	Suitable in NL?
			drill cuttings on coral and sponge species	- May slow operational progress - Difficult for exploration wells - Limited experience on floating drilling platforms and in deep water	
Cuttings Disposal	Injection of drill cuttings into a disposal well (OGP 2003)	Drill cuttings are processed into a slurry and reinjected into a dedicated disposal well.	- Proven technology - Eliminates need for supply vessel to bring waste onshore - Eliminates impact of sedimentation from drill cuttings on coral and sponge species - More economical than disposal onshore	- Requires specialized equipment - Requires viable subsurface injection zone near drilling site - Requires a second well - Requires large storage space on drilling platform - May slow operational progress - Difficult for exploration wells - Limited experience on floating drilling platforms and in deep water	Maybe (limited experience)
Cuttings Disposal	Dispose of drill cuttings onshore (DNV 2013)	Drill cuttings are returned to the platform and separated from drilling muds. They are then transported to shore for disposal.	- Standard treatment of OBM cuttings on all drilling units - Proven and reliable method, extensively used by industry	- Risk of operational delays - Lower than expected performance - Poor weather can significantly impact progress through restrictions to crane operations - Need for storage space on drilling platform - Increase in lifting operations - Requires dedicated personnel - Requires dedicated supply vessel - Increased cost - Increased emissions generated by operations - Not extensively used for WBM cuttings	Maybe (restrictions to crane operations)

Exploration Phase	**Mitigation Measure**	**Description**	**Pros**	**Cons**	**Suitable in NL?**
				- Increased risk of operational problems for larger sections of the well	
Cuttings Disposal	Bulk handling of cuttings to a supply vessel (DNV 2013)	Drill cuttings are brought to surface and transferred to supply vessel through transfer lines for bulk disposal onshore.	- Weather impact is less significant described above - Many crane operations are eliminated - Bulk storage tanks allow for continuous, unrestricted drilling performance if hose can be connected	- In severe weather the transfer hose may be disconnected for long periods of time, suspending drilling operations - Constrained progress of operations - Limited to using inhibited fluids (e.g. glycol) - Limited storage space on platform - Requires dedicated supply vessel - Not suitable for recovery of top hole cuttings without additional equipment - Limited successful experience	Yes
Cuttings Disposal	“Blowing” cuttings to supply vessel (DNV 2013)	Drill cuttings are brought to surface, treated, and blown to the supply vessel through transfer lines with pressurized air.	- Weather impact is less significant - Many crane operations are eliminated - Bulk storage tanks allow for continuous, unrestricted drilling performance if hose can be connected	- In severe weather the transfer hose may be disconnected for long periods of time, suspending drilling operations - Limited storage space on platform - Requires dedicated supply vessel - Requires specialized equipment for blowing system - Needs dedicated personnel to operate - Not suitable for recovery of top hole cuttings without additional equipment	Yes

Exploration Phase	**Mitigation Measure**	**Description**	**Pros**	**Cons**	**Suitable in NL?**
Abandonment	ROV assisted retrieval of anchors (DNV 2013)	Instead of using grappling techniques for retrieving anchors, ROVs and pick-up buoys can be used.	- Minimizes the footprint of impact associated with anchor retrieval, thus reducing impact to corals and sponges	- ROV required for operations - Increased costs	Yes

6. FOLLOW-UP MONITORING

Follow-up monitoring can be required to either verify the predicted effects of exploration activities or determine the effectiveness of mitigation measures which were used during exploration. Baseline surveys may be used to ensure that changes in the chemical and biological aspects of the study area can be accurately recorded. Programs in Norway require baseline surveys before drilling occurs in new areas, as well as in areas where vulnerable benthic species and habitat are present or are believed to be present (Norwegian Environment Agency 2015). In addition, field-specific sites are selected for monitoring potential chemical or biological changes that result from exploration after drilling has begun. Some monitoring programs conducted in Canada suggest that the design would be based on the pre-drill survey, the potential zone of influence as described by dispersion models, and the site's location with respect to sensitive benthic habitats.

While there is an understanding that enhanced monitoring programs should be implemented for areas where coral and sponge species are likely to exist (Buchanan et al. 2003, Norwegian Environment Agency 2015), information on the specific methods that would allow for such enhancements are quite limited, particularly in the NL region. Nonetheless, research from other regions does provide information on some techniques for monitoring these communities that may be suitable. These are described below and summarized in Table 9. It is important to note that like the information contained in Table 8, the suitability of the proposed follow-up monitoring techniques did not take into consideration the geological characteristics of proposed sites, which may limit their application, or the human health and safety risks that could be associated with them.

Although existing Norwegian guidelines suggest that acoustic surveys can be used in place of visual surveys (Norwegian Environment Agency 2015), the sole use of acoustic surveys in NL would be unable to provide information on the specific health of the coral and sponge species. However, the addition of comprehensive visual surveys (e.g. combination of visual and acoustic data) would provide a more detailed picture of the distribution of drill cuttings and mud in this region. At present, visual surveys are the primary method for assessing coral and sponge species in the deep sea (DNV 2013, Yoklavich et al. 2015, 2016, Luter et al. 2017). Like those of pre-drill visual surveys, visual surveys for monitoring purposes can be performed using either an ROV, towed camera system, or AUV. Although scientific studies have also had success with AUVs (Yoklavich et al. 2016), ROVs are generally preferred for detailed inspection applications because of their stability (Ludvigsen et al. 2013, Yoklavich et al. 2015). While the use of high-resolution video equipment is recommended for visual surveys, existing research indicates that even when using high-resolution images, changes in coral polyp behaviour as a result of exposure to drill cuttings could not be identified (DNV 2013). Nonetheless, visual surveys do allow for comparisons of species' ability to cope with excess sediment (e.g. efficiency in removing sediment), changes in coloration, and changes in shape (e.g. loss of branches), which provide useful information about which species are most at risk to increased sedimentation. Comparisons between the pre-drill and follow-up visual surveys, particularly when they are performed using the same pattern, using comparable tools and resolution (e.g. camera, vehicle speed, altitude), are also helpful in validating the dispersion models.

Other non-invasive techniques have been developed for use with subsea video, which allow coral health to be directly quantified from visual surveys. Vad et al. (2017) used imagery software to process still images and provide live to dead layer ratios of *Lophelia pertusa* colonies. Girard and Fisher (2018) used similar software to code *Paramuricea* spp. branches into categories representing varying levels of health, reimaging of the sites between 2011 and 2017 to document changes over time. While these techniques allow for a better understanding of coral health, the large amount of processing they require makes them quite onerous. To account for this, work with Underwater Hyperspectral Imaging (UHI) has been conducted to automate the process. Based on the level of spectral reflectance, images have been classified by habitat (Foglini et al. 2019) or as a function of healthy and unhealthy coral tissues (Holden and Ledrew 1999, Letnes et al. 2019). This work involves the use of hyperspectral cameras which can record the full spectrum of reflected light, thus increasing the amount of information that a single image can provide (Foglini et al. 2019). Historically, *in situ* work with UHI was largely restricted to shallow-water coral reefs (Holden and Ledrew 1999, Gleason et al. 2007). More recent studies have used it for monitoring deep-water coral (Ludvigsen et al. 2013, Johnsen et al. 2016) and sponge habitat (Foglini et al. 2019) but did not use it to measure their health. Although this work has proved promising for use in deep sea applications, it is not yet known if health impacts associated with drill cuttings can be measured using the same hyperspectral techniques described in existing literature (Letnes et al. 2019). Furthermore, inadequate information on the baseline ("healthy") spectral reflectance of many species (Foglini et al. 2019), and limited used on sponge species, suggest that its application in the NL region may be limited at this time.

Because the techniques available for directly assessing coral and sponge health are quite limited, and because visual surveys are unable to detect the presence of chemicals used in drilling muds, existing guidelines also suggest that proponents conduct additional monitoring activities. DNV (2013) describes the importance of collecting current measurements, turbidity measurements, sediment traps, and sediment samples in the study area. Measurements of water currents are important to collect before and during drilling operations as they are key components in developing accurate dispersion models. Turbidity measurements are most useful when collected during drilling operations to determine the amount of turbidity directly associated with drilling and detect the presence and distribution of sediment plumes. Sediment traps can also be deployed throughout the drilling operation and in areas near coral and sponge assemblages, allowing for the direct measurement of drill cuttings. They can be compared to existing PNET for corals and sponges and indicate the likely impact that the drilling will have on these species throughout the study area. Lastly, recommendations indicate that using a corer to retrieve sediment samples both before and after drilling can assist in providing a detailed picture of where drill cuttings and mud have been distributed throughout the area. This can be used to validate the dispersion models, as well as indicate the areas where visual monitoring of corals and sponges should be focused.

Table 9: Review of existing tools that could be employed when monitoring coral and sponge health during exploratory drilling.

Monitoring Timeline	**Tool**	**Description**	**Pros**	**Cons**	**Suitable in NL?**
Before After	Acoustic Survey (Norwegian Energy Agency 2015)	Using a pre-defined survey design, use MBES and SSS to obtain acoustic data of the seafloor within the study area which may be used to identify aggregations of coral/sponge species.	- May be useful for locating aggregations of coral and sponges (depends on resolution of data) - Data for entire study area can be collected more quickly than video - Minimally invasive	- Unable to map small aggregations (common in NL) or individual coral and sponge species - Cannot assess the health of coral and sponge species without direct observation - Does not allow for identification of coral or sponge to species or group level	Moderately (when used with visual survey)
Before After	Visual Survey (ROV) (Yoklavich et al. 2015)	Using a pre-defined survey design, visually map the distribution of corals and sponges in the study area and to assess their health.	- Allows for visual assessment of general coral and sponge distribution, diversity, and health - Might allows for species level identification (depends on imagery resolution) - ROV allows for maneuverability during survey - Might allow the collection of specimens (depends on ROV used) - Minimally invasive	- Challenging to use high-resolution images to identify changes in polyp behaviour after exposure to drill cuttings - Takes longer to acquire data throughout the study area compared to acoustic surveys - Difficulty identifying a suitable parameter to measure coral/sponge health visually - ROV umbilical might pose a risk of potentially damaging corals and sponges (depends on ROV used)	Yes
Before After	Visual Survey (Towed camera system) (Norwegian	Using a pre-defined survey design, visually map the distribution of corals and sponges in	- Allows for visual assessment of coral and sponge distribution, diversity, and health - Minimally invasive	- Challenging to use high-resolution images to identify changes in polyp behaviour after exposure to drill cuttings	No

Monitoring Timeline	Tool	Description	Pros	Cons	Suitable in NL?
	Environment Agency 2015)	the study area and to assess their health.		- Takes longer to acquire data throughout the study area compared to acoustic surveys - Mounting oceanographic equipment is generally not recommended on towed camera systems due to their limited maneuverability - Difficulty identifying a suitable parameter to measure coral/sponge health visually - Umbilical poses a risk of potentially damaging corals and sponges (depends on system used) - Challenging species identification at low taxonomic levels (depends on imagery resolution)	
Before After	Visual Survey (AUV) (Yoklavich et al. 2015)	Using a pre-defined survey design, visually map the distribution of corals and sponges in the study area to assess their health.	- Allows for visual assessment of general coral and sponge distribution, diversity, and health - Can be used to map the exact same areas throughout a drilling campaign for consistency - No umbilical - Minimally invasive	- Has not been used in previous visual surveys for exploratory drilling - High-resolution images have not been able to identify changes in polyp behaviour after exposure to drill cuttings - Difficulty identifying a suitable parameter to measure coral/sponge health visually	Moderately

Monitoring Timeline	Tool	Description	Pros	Cons	Suitable in NL?
				- Path of AUV cannot be altered once it has been deployed - Challenging species identification at low taxonomic levels (depends on imagery resolution)	
Before After	Image Analysis Software (Vad et al. 2017, Girard and Fisher 2018)	Use of images to quantitatively assess the impacts of drilling to coral and sponge species health (i.e. proportion of live vs. dead tissue on colonies).	- Provides a means to quantify coral health - Non-invasive - Can use *in situ* imagery - Proven success in the deep sea	- May not allow for automation - Significant time required for analyzing images - Would only allow for a small number of observations to be processed - Requires high resolution images (enough to allow close-up)	Yes
Before After	Underwater Hyperspectral Imager (UHI) (Holden and Ledrew 1999, Letnes et al. 2019)	Uses machine learning techniques to automate the classification of coral health based on reflectance from a UHI.	- Non-invasive - Capable of automating the process of quantifying coral health - Represents a way to streamline the investigation of impacts on corals	- Only tested on *Lophelia pertusa* in laboratory, and coral reefs *in situ* - Not tested on sponges - Has not yet been used for *in situ* applications in the deep sea - Uncertainties exist whether changes in tissue health resulting from drill cuttings could be determined using this method	Moderately (needs to be specialized for NL region)
Before During	Current Measurements (DNV 2013)	Sensors used to measure water current direction and velocity at specified depths over a certain period.	- Sensors can be set to record for long periods of time	- Cannot directly inform on coral health - Drilling activities are known to change current regimes	Yes

Monitoring Timeline	Tool	Description	Pros	Cons	Suitable in NL?
			- Sensors can measure at a specific depth, or through the whole water column - Useful in verifying dispersion model results		
Before During	Turbidity Measurements (DNV 2013)	Sensors that measure the transparency of the water, which can be used to determine the concentration of sediments in the water column.	- Useful in verifying dispersion model results - Can be used to detect plumes from drilling discharges	- Cannot directly inform on coral health - Measurements can be biased as a result of biological activity near the seabed causing sediment to be redistributed	Yes
During (with analyses after)	Sediment Traps (DNV 2013)	Cylinders which trap sinking particles, allowing for sedimentation levels to be measured directly. Often deployed through free fall, and recovered via acoustic release.	- Certain traps can be pre-set to sample the sediments at specific times/intervals (e.g. every month) - Non-invasive method to infer the sedimentation that coral and sponge species may be exposed to - Small footprint for impact	- If small traps are used it may be difficult to acquire enough sediment for analysis - Needs secondary reference station to account for temporal and spatial changes in sedimentation - Sits on the seafloor, may impact coral and sponge habitat if it lands on them, although in most cases the spatial footprint is very small	Yes
Before After	Sediment Samples (DNV 2013)	Core samples taken to determine the accumulation of drill cuttings throughout the study area.	- One core sample can give enough data for analysis of metals associated with exploratory drilling - Relatively simple method to determine spatial footprint of impact - Minimally invasive	- Would require several cores throughout the study area to delineate the area of impact	Yes

7. RECOMMENDED BEST PRACTICES

Various recommendations were provided in this report to allow for exploratory drilling in the NL region to be performed while avoiding and/or mitigating their effects to coral and sponge species. While many of the recommendations were linked directly with the decision-making framework for avoidance/mitigation of corals and sponges detailed in Figure 23, recommendations beyond the scope of this framework were also put forward. These recommendations suggest that: avoidance and mitigation thresholds should take into consideration the rarity, life history characteristics, and VME status of the coral and sponge species, and be specific to the NL region; industry be responsible for properly collecting data based on the technology chosen to meet the outlined requirements for avoidance and mitigation of corals and sponges, including the performance of literature searches to identify the various methods and analyses required to meet the best practice standards; high-quality *in situ* photos associated with sampled specimens should be obtained; when possible specimen subsamples should be submitted for DNA barcoding analysis and the results to be included in a public database (e.g. GenBank) to corroborate taxa identification by expert. Recommendations specifically pertaining to the decision-making framework outlined in have been summarized below, and are organized to correspond with the flow-chart (Figure 23) presented in Section 5.

AVOIDANCE
PRE-DRILL SURVEYS
MITIGATION
FOLLOW-UP MONITORING

RELOCATION

- Exploratory drilling activities should be relocated from areas that have been identified based on significant densities of corals or sponges, specifically SiBAs and VME habitats.
- Outside of SiBAs and VME habitats, exploratory drilling activities should take place at least 2 km away from locations where pre-drill surveys have identified coral and/or sponge species at or above significant density thresholds. Drilling discharge dispersion models/zone of influence predictions should be used to determine if a larger radius is necessary.
- The area of impact (1.5 mm PNET) should not overlap any existing special areas (SiBAs or VME habitats), as these can still be impacted through the dispersal of sediment and/or contaminants.

DISPERSION MODELS

- Dispersion models should be developed using the best available 3-dimensional current estimate.
- Dispersion models should consider seasonal and inter-annual variations of ocean currents.
- Dispersion models should track settlement of the largest possible fraction of suspended material.
- When available, previously validated drilling discharge dispersion models from relevant exploratory drilling sites should be used to inform model configuration for subsequent projects.
- Sediment classes used in dispersion models should be representative of the proposed drill site.
- Benthic boundary layer processes should be included in dispersion models.
- Sensitivity analyses should be performed on all relevant dispersion model parameters.

BASELINE SURVEY

- Baseline surveys should be conducted in previously un-surveyed areas, and in areas where coral and sponge species are present or are predicted to be present.
- Information on currents, turbidity, and sediment (rates and samples), should be collected as part of baseline and pre-drill surveys.
- Control sites (upstream/downstream) are recommended outside the expected zone of influence.

VISUAL SURVEY

- All proposed drilling sites should undergo a thorough, high-resolution, visual survey (e.g. HD, 4K resolution or best available technology).
- Pre-drill acoustic data (bathymetry and backscatter) should be collected at a high enough resolution that potential coral and sponge structures in the NL region can be identified (e.g. SAS or similar available technology), if these surveys are meant to be used to identify such structures.
- Potential coral and sponge habitat identified through acoustic surveys should be ground truthed through visual surveys.
- A hybrid survey should be completed that integrates 1) an acoustic survey that can identify bottom types (i.e. potential habitat for corals and sponges) and 2) a visual survey that can detect and allow for the identification of corals and sponges.
- Visual survey design should consider the proposed footprint of positioning equipment and associated positional uncertainty (e.g. dynamic positioning transponders, anchors, mooring lines).
- Visual survey design should be conducted in a clover-leaf pattern and the length of transect lines should be based on the 1.5 mm PNET footprint identified by dispersion models. Video should be consistently collected along the entire length of each transect line (i.e. maintaining video quality).
- Visual surveys should be designed to allow for measurement of abundance and density (e.g. consider camera angle, vehicle's altitude and speed) of corals and sponges surrounding a proposed drill site.
- Surveys should be conducted at suitable speeds (0.5 kts) with the camera 1–2 m above the seafloor and should be equipped for *in situ* measurement, taxonomic identification, and sample collection of reference specimens (i.e. that can confirm species identification from video).
- Due to the patchy nature of coral and sponge habitat, a qualified individual should review all video data (i.e. not just a portion of the video) collected prior to exploratory drilling and information regarding significant densities should be shared with DFO Science.
- Standardized training is recommended to qualify individuals to identify corals and sponges from visual survey data.
- Taxa should not be identified at the species level using visual imagery unless a reference specimen has been collected to verify identification.
- In cases where the video analyst has high confidence on the identification of common species from imagery, taxa can be tentatively identified at lower taxonomic levels.

POSITIONING

- Positioning systems should reduce the potential for impact to corals and sponges as much as possible. If anchors are necessary, they should be deployed and retrieved by ROV when possible.
- If anchors are used, methods to reduce the impact that mooring lines will have (e.g. buoyancy) should be employed where possible.

DRILLING

- Methods that limit the amount of sedimentation during top hole drilling (e.g., not using water jetting) are recommended in areas where corals and sponges are present, where technically feasible.
- If cutting transport systems (CTS) are used, the proposed equipment corridor, as well as the location of disposal site, should be subject to visual inspection to ensure significant densities of coral and sponge species are not present.
- If cuttings piles are generated, subsequent disturbance of these areas should be limited to prevent the redistribution of contaminated sediments.
- When possible, the selection of the type of drilling muds should be justified based on the least potential impact to corals and sponges.
- When possible, the release of drill cuttings at sea should be eliminated or reduced.
- When possible, selection of disposal methods for drill cuttings should be based on the least potential impact to corals and sponges.
- Back-up mitigation techniques should be identified in the event that the primary option is not performing as required.
- Mitigation techniques/tools should be tolerant to weather conditions in the Northwest Atlantic.

ABANDONMENT

- Instead of using grappling techniques for retrieving anchors, ROVs and pick-up buoys should be used where practicable and feasible to reduce bottom impacts.
- Impacts to corals and sponges should be minimized where possible when the well-head is being removed (e.g. utilize internal shearing if practicable).

ENHANCED MONITORING

- Enhanced follow-up monitoring should be conducted in areas where coral and sponge species are present.
- Specific sites should be selected within the zone of influence and used to monitor physical, chemical, and biological changes that may occur while exploratory drilling is being conducted.
- Sites should be laid out in a radial pattern surrounding the proposed drilling site and consider the prevailing bottom current.
- Information on currents, turbidity, and sediment (rates and samples), should be collected during follow-up monitoring.
- Sediment cores should be collected to provide a detailed picture of sedimentation rates during drilling programs.
- Visual surveys, using ROVs, should be conducted as part of follow-up monitoring.

- Enhanced follow-up monitoring should implement the use of imagery analysis to potentially allow the assessment of changes in coral and sponge health over time.
- The same survey design and technique should be used in follow-up surveys as were used in pre-drill surveys to allow for comparison.
- Control sites (upstream/downstream) are recommended outside the expected zone of influence. Sites should be the same as those used in the pre-drill baseline survey.

8. CONCLUDING REMARKS

While there is limited information available about the specific impacts of exploratory drilling on coral and sponge species in the NL region, a literature review found that the effects caused by these activities could be wide-spread and long-lasting (Malecha and Stone 2009, Schönberg 2016, Cordes et al. 2016). In general, exposure to exploratory drilling activities has led to reductions in abundance, biomass, and diversity of benthic taxa, as a result of chemical and mechanical damage (Ellis et al. 2012, Gates and Jones 2012, Paine et al. 2014). Considering the roles these species play in supporting biodiversity and aiding organic cycling in the deep-sea (Baker et al. 2012, Beazley 2013a, Pham et al. 2019, Pierrejean et al. 2020), it is imperative to ensure that activities that put them at risk undergo thorough assessment to avoid and mitigate potential associated impacts.

The lack of information on specific impacts to coral and sponge species has led oil and gas operators in the NL region to proceed with exploratory drilling activities, but with limited avoidance and mitigation of associated effects. This report aims to build on the existing framework, to help guide the development of standard operating procedures for the industry to apply moving forward. A key focus of this report was the application of the “mitigation hierarchy” when considering whether oil and gas exploration should proceed at a proposed location. Under this hierarchy, the primary goal is to avoid harm, while secondary and tertiary options are to mitigate, and offset harm, respectively.

The requirement to apply avoidance or mitigation measures relies largely on the information collected during the pre-drill survey. However, a review of the existing standards applied in the NL region suggested that many small (<30 cm in height and/or width) coral and sponge species may go undetected during pre-drill surveys, putting them at risk for damage and mortality. To address this, a literature review was conducted, and recommended improvements to pre-drill survey methodologies were outlined within the report (Table 6). Key recommendations included: the collection of acoustic data (e.g. MBES, SSS) at resolutions which would be capable of capturing small coral and sponge species that are common in the NL region; standardization of visual data collection with increased coverage and a variable extent based on a 1.5 mm PNET; improved methodologies for producing dispersion models; and the development of provision significant density thresholds for coral and sponge groups to determine whether avoidance or mitigation measures are required at each site.

The findings of this report provide detailed recommendations on where exploratory drilling activities should be avoided, and, in areas where avoidance is not required, outline the requirements for mitigation. In general, the avoidance and mitigation measures outlined in the report describe a variety of methods which would eliminate or reduce the amount of physical contact with the seafloor and/or the amount of sediment generated on-site as a result of exploration activities. Existing literature also recognizes that enhanced follow-up monitoring programs should be implemented for areas where coral and sponge species exist, or are likely to exist (Buchanan et al. 2003, Norwegian Environment Agency 2015). As such, the report outlined various methodologies that have been used in other regions to capture the impacts that oil and gas exploration have on coral and sponge health (Table 9).

Finally, considering that there are still significant gaps in the knowledge of corals and sponges within the NL region, that the potential impacts of exploratory drilling are not fully understood, and that cumulative effects of anthropogenic activities were not considered in this report, it is recommended that density thresholds and best practices should continue to be reviewed as new information becomes available.

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APPENDIX A. LIST OF ACRONYMS

Acronym	Definition
AOI	Area of Interest
AUV	Autonomous Underwater Vehicle
BOP	Blowout Preventer
CAN	Conductor Anchor Nodes
CEAA	Canadian Environmental Assessment Agency
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CO_2	Carbon Dioxide
CTS	Cuttings Transport System
DFO	Fisheries and Oceans Canada
DOC	Dissolved Organic Carbon
DP	Dynamic Positioning
EA	Environmental Assessment
EBSA	Ecologically and Biologically Significant Area
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
EMOBM	Enhanced Mineral Oil-Based Mud
FAO	Food and Agriculture Organization
FFHPP	Fish and Fish Habitat Protection Program
GIOPS	Global Ice Ocean Prediction System
GIS	Geographic Information System
GLORYS	Global Ocean Reanalysis and Simulation
HD	High Definition
HYCOM	Hybrid Coordinate Ocean Model
IAAC	Impact Assessment Agency of Canada
KDE	Kernel Density Estimation
NAC	North Atlantic Current
NAFO	Northwest Atlantic Fisheries Organization
NH_4^+	Ammonium
NL	Newfoundland and Labrador
NO_2^-	Nitrite
NO_3^-	Nitrate
NOROG	Norske Olje & Gass (Norwegian Oil & Gas)
NRA	NAFO Regulatory Area
NS	Nova Scotia

Acronym	Definition
NSRF	Northern Shrimp Research Foundation
MBES	Multibeam Echosounder
MOU	Memorandum of Understanding
MPA	Marine Protected Area
MR	Marine Refuge
OBM	Oil-Based Mud
OECM	Other Effective Area-Based Conservation Measure
OGP	International Association of Oil and Gas Producers
OWTG	Offshore Waste Treatment Guidelines
PNET	Probable No-Effect Threshold
RIOPS	Regional Ice Ocean Prediction System
RMR	Riserless Mud Recovery
ROPOS	Remotely Operated Platform for Ocean Sciences
ROV	Remotely Operated Vehicle
RV	Research Vessel
SAS	Synthetic Aperture Sonar
SiBA	Significant Benthic Area
SBM	Synthetic-Based Mud
SDM	Species Distribution Model
SSS	Side Scan Sonar
THC	Total Hydrocarbon Content
TSS	Total Suspended Solid
UHI	Underwater Hyperspectral Imaging
VME	Vulnerable Marine Ecosystem
WBM	Water-Based Mud
WHOI	Woods Hole Oceanographic Institute
3D	Three Dimensional

APPENDIX B. CORAL GROUP DEFINITIONS

Table A1: Descriptions of coral groups listed in this document. Attachment refers to surface of attachment, with crosses indicating presence. The number of crosses indicates the prevalence of a hard or soft attachment surface for a specific group based on the majority of taxa found in the region. State refers to the physical state of a sample obtained from trawl surveys, which influences abundance and biomass estimates.

Group	**Description**	**Attachment**		**State**	**Notes**
		Soft	Hard		
Large gorgonians	Arborescent or fan-shaped corals in the order Alcyonacea with a proteinaceous and/or calcareous inner axis (skeleton). Large gorgonians can attain heights >2 m.	+	++	Fragmented	Often fragmented in trawl surveys. Generally found attached to hard substrate, but the bamboo coral *Keratoisis flexibilus* can be found directly on soft substrate (e.g. Neves et al. 2015, published as *Keratoisis* sp.).
Small gorgonians	Same as large gorgonians, but smaller in their adult stages (usually <30 cm in height). This group is mainly represented by the bamboo coral *Acanella arbuscula* and the whip-like coral *Radicipes* spp.	++	+	Fragmented	Although *Radicipes* spp. and *Chrysogorgia* spp. can reach heights >30 cm, here they are grouped with the small gorgonians because they are delicate and do not form massive structures like large gorgonians. *Acanella arbuscula* is generally found directly on soft substrate, but the other small gorgonians are usually found attached to hard substrate.
Soft corals	Corals in the order Alcyonacea without an inner axis. They have a soft body supported by a hydrostatic skeleton and small $CaCO_3$ structures (i.e. sclerites) embedded in their tissue. This group is mainly represented by the families Nephtheidae and Alcyoniidae (mushroom corals), but includes delicate forms such the stoloniferous (creeping) *Clavularia* spp.	+	++	Whole	Generally found attached to hard substrate, but *Gersemia fruticosa* and *Heteropolypus* spp. can be found directly on soft substrate.
Sea pens	Corals in the order Pennatulacea. Include both quill pen (e.g. *Pennatula* spp.), and whip-like morphologies (e.g. *Halipteris* spp., *Protoptilum* spp.).	++	-	Whole	Mainly found on soft substrate. They are permanently partly buried in the sediment (i.e. peduncle). Some species can entirely withdraw into the substrate (e.g. *Pennatula aculeata*, Langton et al. 1990) following cues not yet completely understood, but with a potential to influence their catchability in trawls.
Black corals	Corals in the order Antipatharia. They have a wire-like organic skeleton composed of concentric layers of protein and chitin. Colonies range in shape from branching (e.g.	-	++	Fragmented	Less commonly found in the trawl surveys in the region in comparison to other corals.

Group	Description	Attachment		State	Notes
		Soft	Hard		
	Stauropthes sp.), to feather-like (e.g. *Bathypathes* sp.) or whip-like (e.g. *Stichopathes* sp.) morphologies. Some species can exceed 1 m in height, but most are <50 cm.				
Cup corals	Solitary corals in the order Scleractinia. They have a $CaCO_3$ skeleton and can be found free-living (unattached) on soft bottoms or attached to hard substrates. This group is mainly represented by *Flabellum* spp., primarily *F. alabastrum*, a free-living species found on soft bottoms.	++	+	Whole	Individuals are small (usually <5 cm in height) but can be found in aggregations. Other species included in this group are rare and/or are found infrequently in the trawl surveys (e.g. *Vaughanella* sp., *Javania* sp., *Fungiacyathus* sp.).
Hydrocorals	Corals in the order Anthoathecata (class Hydrozoa). They have $CaCO_3$ skeletons and can have branching or encrusting morphologies or form lamellate sheets. Colonies found in this region are usually branching in morphology.	-	+	Fragmented	Rarely found in the trawl surveys in the region. Species observed in the region have a branching morphology and are <30 cm in height.

APPENDIX C. CORAL AND SPONGE SPECIES IN NL

Table A2: List of cold-water coral and sponge species known to exist in the NL region.

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
Black Corals	Anthozoa	Antipatharia	-	**Antipatharia sp.:** Arborescent growth form; height 50 cm (Baker et al. 2012).	Baker et al. 2012, Wareham et al. 2012
			Antipathidae	***Stichopathes*** **sp.:** Whip like with spiral growth form and holdfast; height 80 cm (Kenchington et al. 2009).	Murillo et al. 2011, 2016b, Wareham et al. 2012
			Leiopathidae	***Leiopathes*** **sp.:** Arborescent growth form; height <1 m (Wareham et al. 2012, De Clippele et al. 2019).	Murillo et al. 2011, Wareham et al. 2012
			Schizopathidae	***Bathypathes patula*****:** Monopodial growth form; height 15 cm (Molodtsova 2006, Baker et al. 2012).	Baker et al. 2012, Wareham et al. 2012
				Bathypathes **spp.:** Monopodial growth form; height <50 cm (Moldtsova 2006, V. Hayes pers. comm.).	Wareham 2009
				Schizopathidae spp.: Whip-like with spiral growth form; height >60 (Molodtsova 2006, Baker et al. 2012).	Baker et al. 2012
				Stauropathes arctica**:** Synonym *Bathypathes arctica*. Arborescent, bushy growth form densely branched on thin stem with holdfast; height <1 m (Molodtsova 2006, V. Hayes pers. comm.).	Gass 2005, Gass & Wilson 2005, Wareham & Edinger 2007, Wareham et al. 2012, Murillo et al. 2016b
Black Corals	Anthozoa	Antipatharia	Schizopathidae	***Stauropathes*** **cf.** ***punctate*****:** Arborescent, bushy or fan-like, growth form with holdfast; height <1 m (Molodtsova 2006, V. Hayes pers. comm.).	Wareham et al. 2012
				Telopathes magnus**:** Long arborescent growth form with holdfast; height >1 m (MacIsaac et al. 2013).	Beazley et al. 2013

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
Cup Corals		Scleractinia	Fungiacyathidae	***Fungiacyathus (Bathyactis) marenzelleri*: Hard disc-like growth form; height ~1 cm, width ~2 cm (V. Hayes pers. comm.).	V. Hayes pers. comm.
			Caryophylliidae	***Caryophyllia (Caryophillia) ambrosia*:** Cup-like growth form; height ~3 cm, width ~3 cm (Cairns 1981).	V. Hayes pers. comm.
				***Desmophyllum dianthus*:** Hard with chalice-like growth form; height 7 cm, width 5 cm (Cairns 1981).	Wareham & Edinger 2007, Baker et al. 2012
				***Vaughanella margaritata*:** Hard cup-like growth form; height < 3 cm, width ~ 3 cm (V. Hayes pers. comm.).	Wareham & Edinger 2007, Baker et al. 2012
			Flabellidae	***Flabellum (Ulocyathus) alabastrum*:** Hard cup-like growth form; height <5 cm (V. Hayes pers. comm.).	Wareham & Edinger 2007, Baker et al. 2012
				***Flabellum (Ulocyathus) angulare*:** Hard cup-like growth form; height <4 cm, width <6 cm (Cairns 1981).	Beazley & Kenchington 2015
				***Flabellum (Ulocyathus) macandrewi*:** Hard cup-like growth form, fragments easily; height <2 cm (Cairns 1981).	Wareham 2009, Baker et al. 2012
Cup Corals	Anthozoa	Scleractinia	Flabellidae	***Javania cailleti*:** Chalice-like growth form; height ~1 cm, width ~8 cm (V. Hayes pers. comm.).	Wareham 2009, Baker et al. 2012
Reef Corals			Caryophylliidae	***Lophelia pertusa*:** Recently identified as *Desmophyllum pertusum*. Hard branching growth form with branches crossed and fused; height varies from meters to 100s of meters (see Wheeler et al. 2007).	This species has not been documented in the NL Region. Documented on the Scotian Shelf (Buhl-Mortensen et al. 2017) and SW Greenland (Kenchington et al. 2016).
Large Gorg		Alcyonacea		**Alcyonacea spp.:** Published as Gorgonian spp. Arborescent growth form; height 50 cm (Baker et al. 2012).	Baker et al. 2012

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
			Acanthogorgiidae	***Acanthogorgia armata***: Dense arborescent growth form with holdfast; height 50 cm (Wareham & Edinger 2007, Baker et al. 2012).	Baker et al. 2012, Murillo et al. 2016b
			Chrysogorgiidae	***Chrysogorgia* spp.**: Bottle brush or arborescent growth forms; height <30 cm (V. Hayes pers. comm.).	Meredyk et al. 2020
Large Gorgonians	Anthozoa	Alcyonacea	Coralliidae	***Corallium* spp.**: Hard skeleton with arborescent growth forms; height <30 cm (V. Hayes pers. comm.).	Beazley et al. 2013
			Isididae	**Isididae spp.**: Arborescent growth forms with jointed axis; height 30 cm (Baker et al. 2012).	Baker et al. 2012, Meredyk et al. 2020
				Keratoisis* cf. *siemensii: Arborescent growth form with jointed axis.	Murillo et al. 2016b
				Keratoisis flexibilus: Published as *Keratoisis* sp. Dense arborescent growth form, with thin branches and jointed axis; height <1 m (Neves et al. 2015).	Neves et al. 2015, Saucier 2016
				Keratoisis grayi: Published as *Keratoisis ornata*. Arborescent growth form with thick branches, jointed axis; height 215 cm; width 250 m (Baker et al. 2012, 2019).	Edinger et al. 2007, Wareham & Edinger 2007, Baker et al. 2012
				***Keratoisis* sp.**: Arborescent growth form with jointed axis.	Murillo et al. 2011, Beazley et al. 2013
				***Lepidisis* sp.**: Whip-like growth form with jointed axis; height 30 cm (Baker et al. 2012).	Baker et al. 2012, Miles 2018

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
			Plexauridae	***Paramuricea grandis*: ** Large arborescent or fan-like growth form; height <1 m (Wareham & Edinger 2007).	Murillo et al. 2016b
				***Paramuricea placomus*: ** Note published as P. grandis. Large arborescent or fan-like growth form; height <1 m (Wareham & Edinger 2007).	Edinger et al. 2007, Wareham & Edinger 2007
Large Gorgonians	Anthozoa	Alcyonacea	Plexauridae	***Paramuricea* spp.:** Large arborescent or fan-like growth forms; up to 4 spp. (Radice et al. 2016); height 45 cm (Baker et al. 2012).	Baker et al. 2012, Murillo et al. 2011, 2016b, Radice et al. 2016
				***Placogorgia* sp.:** Arborescent or fan-like growth form.	Murillo et al. 2011, 2016b; V. Hayes pers comm.
			Paragorgiidae	***Paragorgia arborea*: ** Large arborescent or fan-like growth form, with thick branches; height <5 m (Baker et al. 2012, Buhl-Mortensen et al. 2019).	Gass & Wilson 2005, Wareham & Edinger 2007, Baker et al. 2012, Miles 2018, Meredyk et al. 2020
				***Paragorgia johnsoni*: ** Large arborescent or fan-like growth form; height ~1 m (V. Hayes pers. comm.).	Murillo et al. 2011, 2016b
			Primnoidae	***Primnoa resedaeformis*: ** Hard but flexible arborescent growth form with dichotomous branching; height 1 m (Bayer 1983, Buhl-Mortensen et al. 2016).	Gass & Wilson 2005, Wareham & Edinger 2007, Murillo et al. 2016b
Small Gorgonians			Anthothelidae	***Anthothela grandiflora*: ** Densely branching colonies; height <10 cm (V. Hayes pers. comm.).	Wareham & Edinger 2007, Murillo et al. 2016b
			Chrysogorgiidae	***Radicipes gracilis*: ** Thin, whip-like growth form with rhizoid holdfast; height <1 m (Wareham & Edinger 2007).	Wareham & Edinger 2007, Baker et al. 2012, Murillo et al. 2016b
				***Chrysogorgia agassizii*: ** Bottle brush-like growth form; height 30 cm (Bayer 1983, Baker et al. 2012).	Wareham 2009, Baker et al. 2012

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
Small Gorgonians	Anthozoa	Alcyonacea	Isididae	***Acanella arbuscula*****:** Dense but stout arborescent growth form with jointed axis and rhizoid holdfast; height <30 cm (Baker et al. 2012).	Wareham & Edinger 2007, Wareham 2009, Baker et al. 2012, Murillo et al. 2016b
			Primnoidae	***Narella* cf. *laxa*****:** Arborescent growth form; height <30 cm (V. Hayes pers. comm.).	Miles 2018
				Parastenella atlantica**:** Arborescent growth form, planar with some branching; height 10 cm, width 10 cm (Cairns 2010).	Wareham & Edinger 2007, Wareham 2009, Murillo et al. 2016b
			Plexauridae	***Swiftia* sp.:** Arborescent, bushy or fan-like growth forms, holdfast small; height <30 cm (V. Hayes pers. comm.).	Murillo et al. 2011, 2016b, Miles 2018
Hydrocorals		Anthoathecata	Stylasteridae	***Stylaster erubescens gronenlandicus*****:** Hard arborescent uniplanar growth forms thickened branches; height 8 mm (Zibrowius & Cairns 1992).	V. Hayes pers. comm.
				***Stylaster* spp.:** Hard arborescent uniplanar growth forms thickened branches; height 12 cm, width 18 cm (V. Hayes pers. comm.).	V. Hayes pers. comm.
Sea Pens		Pennatulacea	Anthoptilidae	***Anthoptilum grandiflorum*****:** Colonies whip-like with '?' shape; height 60 cm (Baillon et al. 2016).	Wareham & Edinger 2007, Wareham 2009, Baker et al. 2012, Murillo et al. 2016b
				Anthoptilum murrayi**:** Note sister species to *A. grandiflorum*): Colonies whip-like with '?' shape; height <50 cm (Williams 1995, V. Hayes pers. comm.)	V. Hayes pers. comm.
Sea Pens	Anthozoa	Pennatulacea	Funiculinidae	***Funiculina quadrangularis*****:** Delicate whip-like growth form; height <1 m (V. Hayes pers. comm.).	Wareham & Edinger 2007, Wareham 2009, Baker et al. 2012, Murillo et al. 2016b

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
			Halipteridae	***Halipteris* cf. *christii***: Flexible, whip-like growth form; height 12 cm (Nutting 1912).	Altuna & Murillo 2012, Murillo et al. 2011, 2016b
				Halipteris finmarchica: Firm but flexible, whip-like growth form; height <2.5 m but typically <1 m. (Baillon et al. 2016, V. Hayes pers. comm.).	Wareham & Edinger 2007, Baker et al. 2012, Murillo et al. 2016b
				***Halipteris* sp.**: Flexible, whip-like growth form. (Williams 1995).	Beazley 2013b, Beazley & Kenchington 2015
			Kophobelemnidae	***Kophobelemnon* sp.**: Small club-shaped growth form with majority of colony buried (V. Hayes pers. comm.)	Beazley et al. 2013b, Beazley & Kenchington 2015
				Kophobelemnon stelliferum: Small club-shaped growth form with majority of colony buried; height <15 cm (V. Hayes pers. comm.).	Wareham & Edinger 2007, Wareham 2009, Baker et al. 2012, Murillo et al. 2016b
			Pennatulidae	***Pennatula aculeata***: Note published as *Pennatula phosphorea*. Flexible feather-shaped growth form; height <30 cm (Williams 1995, Baillon et al. 2016).	Wareham & Edinger 2007, Wareham 2009, Murillo et al. 2016b
				Pennatula grandis: Recently changed to *Ptilella grandis*. Flexible feather-shaped growth form with bulbous base; height <30 cm (Williams 1995).	Wareham & Edinger 2007, Baker et al. 2012, Murillo et al. 2016b
Sea Pens	Anthozoa	Pennatulacea	Protoptilidae	***Protoptilum carpenteri***: Slender whip-like growth form, able to withdraw into sediment; height <30 cm (V. Hayes pers. comm.).	Wareham 2009, Murillo et al. 2016b
				Distichoptilum gracile: Flexible slender, whip-like growth form (Williams 1995).	Wareham & Edinger 2007, Wareham 2009, Murillo et al. 2016b
			Scleroptilidae	***Scleroptilum grandiflorum***: Delicate club-shaped growth form; height <5 cm (Williams 1995, V. Hayes pers. comm.).	B. Neves pers. comm.

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
			Umbelluliidae	***Umbellula lindahli*****:** Long whip-like growth form with terminal cluster of polyps; height <1 m (Williams 1995, B. Neves pers. comm.).	Wareham & Edinger 2007, Wareham 2009, Murillo et al. 2016b
			Virgulariidae	***Virgularia mirabilis*****:** Flexible slender, whip-like growth form (Williams 1995).	Murillo et al. 2011; Murillo et al. 2016b, V. Hayes pers. comm.
			-	**Pennatulacea spp.:** Whip or club like growth forms.	Wareham & Edinger 2007, Wareham 2009
Soft Corals (including Mushroom Corals)	Anthozoa	Alcyonacea	Alcyoniidae	***Anthomastus grandiflorus*****:** Mushroom-like growth form; height 5–10 cm (Wareham & Edinger 2007, V. Hayes pers. comm.).	Wareham & Edinger 2007, Altuna et al. 2014, Murillo et al. 2016b
				Anthomastus gyratus**:** Mushroom-like growth form; height <5 cm (Molodtsova 2013, V. Hayes pers. comm.).	V. Hayes and J. Murillo, pers. comm.
				Anthomastus **spp.:** Mushroom-like growth forms; height 12 cm, width 7.5 cm (Bayer 1983, Verrill 1913).	Murillo et al. 2011, Baker et al. 2012, Murillo et al. 2016b
				Pseudoanthomastus agaricus**:** Synonym *Anthomastus agaricus*. Mushroom-like with long stalk; height <8 cm (V. Hayes pers. comm.).	Murillo et al. 2016b, Altuna et al. 2014, Murillo et al. 2016b, V. Hayes pers. comm.
				Pseudoanthomastus mariejoseae**:** Mushroom-like with long stalk; height <5 cm (Molodtsova 2013). Published as *Pseudoanthomastus* sp. (Murillo et al. 2016b).	Murillo et al. 2016b, V. Hayes pers. comm.
				Pseudoanthomastus **sp.:** Mushroom-like with long stalk; height <5 cm (Altuna et al. 2014).	Altuna et al. 2014, Murillo et al. 2016b
				Heteropolypus sol**:** Synonym *Heteroplypus insolitus*. Mushroom-like growth form; height <4 cm, width ~3 cm (Bayer 1983, Molodtsova 2013).	Baker et al. 2012, Altuna et al. 2014, Murillo et al. 2016b

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
			Clavulariidae	***Clavularia borealis***: Soft creeping growth form; height <5 cm (V. Hayes pers. comm.).	V. Hayes pers. comm.
				Clavulariidae spp.: Soft creeping growth forms; height <5 cm (V. Hayes pers. comm.).	Murillo et al. 2011, 2016b
				Telestula septentrionalis: Soft creeping growth form; height <5 cm (Madsen 1944).	Madsen 1944, Murillo et al. 2011, 2016b
Soft Corals (including Mushroom Corals)	Anthozoa	Alcyonacea	Nephtheidae	**Nephtheidae indet.:** Soft arborescent growth form with hyrdostatic skeleton; height <30 cm (V. Hayes pers. comm.).	Wareham & Edinger 2007, Wareham 2009
				Drifa glomerata: Soft arborescent growth form with hyrdostatic skeleton; height <20 cm (V. Hayes pers. comm.).	Murillo et al. 2016b, Neves et al. 2020
				Duva florida: Synonym *Capnella florida*. Soft arborescent growth form with hyrdostatic skeleton; height <30 cm (V. Hayes pers. comm.).	Wareham & Edinger 2007, Wareham 2009, Baker et al. 2012
				***Pseudodrifa* sp.:** Soft arborescent growth form with hyrdostatic skeleton; height <10 cm (B. Neves pers. Comm.). Published as *Drifa flavescens* (Murillo et al. 2016b).	Murillo et al. 2016b, B. Neves pers. comm.
			Alcyoniidae	***Gersemia fruticosa***: Soft arborescent growth form with hyrdostatic skeleton; height <20 cm (V. Hayes pers. comm.).	Murillo et al. 2016b
				Gersemia rubiformis: Soft glomerate growth form with hyrdostatic skeleton; height <5 cm (V. Hayes pers. comm.).	Wareham & Edinger 2007, Murillo et al. 2016b
Sponges	Calcarea	Leucosolenida	Sycettidae	***Sycon* sp.:** Small barrel shaped sponge with long tuft; height 1–9 cm (Best et al. 2010, Dinn & Leys 2018).	Fuller 2011, Best et al. 2010, Dinn & Leys 2018
Sponges	Demospongiae	-	-	***Desmospongiae sp.**	Fuller 2008, Murillo et al. 2012, 2016b
		Axinellida	Axinellidae	***Axinella arctica***: Erect cup or fan-shaped stalked sponge; height 5–25 cm, width ~5–10 cm (Dinn & Leys 2018).	Dinn & Leys 2018

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
				***Axinella* sp.**	Murillo et al. 2012, 2016b
				Phakellia robusta: Thin upright fan-shaped sponge.	Fuller 2011
				***Phakellia* spp.**: Erect cup or fan-shaped sponge with stalk; height 20 cm (Best et al. 2010).	Best et al. 2010, Fuller 2011, NAFO 2014, Murillo et al. 2016b, Dinn & Leys 2018
				Phakellia ventilabrum: Erect fan or cup shaped sponge; height ~20 cm (Ackers & Moss 2007, ICES 2010).	Fuller 2011
				Plicatellopsis bowerbanki: Species is not in WoRMS (Dinn 2019), instead *Phakellia bowerbanki*. Erect vase shape sponge, can form a funnel at the base; height ~15 cm, width ~30 cm (Dinn 2019).	V. Hayes pers. comm. data
			Raspailiidae	***Janulum spinispiculum***: Encrusting with oscula protrude from crust on raised, nearly cylindrical portions; height <2 cm, width >15 cm (Dinn & Leys 2018).	Dinn & Leys 2018
			Stelligeridae	***Paratimea* sp.**	Murillo et al. 2016b
Sponges	Demospongiae	Biemnida	Biemnidae	***Biemna variantia***: Cushion shaped, encrusting sponge; height 15 cm, width 15 cm (Dinn & Leys 2018).	Best et al. 2010, Fuller 2011, Dinn & Leys 2018, V. Hayes pers. comm. data
		Clionaida	Clionaidae	***Cliona* spp.**: Small encrusting sponges; width ~20 cm (Best et al. 2010).	Best et al. 2010

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
		Dendroceratida	Dictyodendrillidae	***Spongionella pulchella*: ** Upright thickly platy or branching with a short stalk; height 5–10 cm, width 5–10 cm (MSIP 2020).	Best et al. 2010, Murillo et al. 2016b
				***Spongionella* sp.**	Fuller 2011
		Desmacellida	-	*__Desmacellida sp.__	Murillo et al. 2016b
			Desmacellidae	***Desmacella annexa*:** See *Stryphnus ponderosus*. Massive, encrusting or erect sponge; height 5^+ cm (MSIP, 2020).	Cárdenas & Rapp 2015
		Haplosclerida	-	*__Haplosclerida sp.__	Murillo et al. 2016b
			Chalinidae	*___Haliclona___ __spp.:__ Erect, finger-shaped stalked sponges.	Best et al. 2010, Fuller 2011, *Murillo et al. 2016b, Dinn & Leys 2018
				***Cladocroce spatula*:** Erect, fan-shaped sponge or with flat lobes, and stalked; height 35 cm, width >20 cm (Dinn 2019).	V. Hayes pers. comm.
Sponges	Demospongiae	Haplosclerida	Chalinidae	***Haliclona (Flagellia) porosa*:** Massive, cushion shaped sponge; height 2 cm, width 2 cm (Dinn & Leys 2018).	Dinn & Leys 2018
				***Haliclona (Flagellia)* sp.:** Massive, encrusting sponge with faintly raised oscular lobes. Very friable; height 10 cm, width 10 cm (Dinn & Leys 2018).	V. Hayes pers. comm.
			Dyctodendrillidae	***Haliclona (Gellius)* sp.:** Note published as Gellius sp.	Murillo et al. 2016b
				***Haliclona (Haliclona) oculata*:** Erect, long branching growth form with rounded tips and central stalk; height 30^+ cm, width 20 cm (Dinn 2019).	V. Hayes pers. comm.
				***Haliclona (Haliclona) urceolus*:** Erect, tubular to chimney shaped sponge; height <10 cm (Dinn & Leys 2018).	Fuller 2011, Dinn & Leys 2018, V. Hayes pers. comm.

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
			Niphatidae	***Hemigellius arcofer***: Erect sponge, thick fan or vase shaped; height 30 cm, width 20 cm (Dinn 2019).	Fuller 2011, Dinn 2019, V. Hayes pers. comm.
		Heteroscleromorpha	-	***Heteroscleromorpha* sp.:** Published as *Halichondrida* indet).	Murillo et al. 2012
Sponges	Demospongiae	Merliida	Hamacanthidae	***Hamacantha* sp.**	Murillo et al. 2016b
		Poecilosclerida	-	***Poecilosclerida sp.:** Note genus *Myxillina* discontinued (Murillo et al. 2012).	Murillo et al. 2012, 2016b
			Acarnidae	***Iophon piceum***: Note NAFO (2014) spelling error as *Lophon piceum*. Erect, leaf or cup-shaped sponge with irregular rim and a grooved surface; height 16 cm (Arndt 1935).	Murillo et al. 2012, 2016b, NAFO 2014, Dinn & Leys, 2018, V. Hayes pers. comm.
				***Iophon* sp.:** Most likely erect fan shaped sponge, always collected in small pieces.	Fuller 2011
			Cladorhizidae	***Asbestopluma (Asbestopluma) pennatula***: Erect feather shaped sponge with flexible stem; height 25 cm, width 1–3 mm (Hestetun et al. 2017).	Hestetun et al. 2017
				Asbestopluma (Asbestopluma) ruetzleri: Erect feather shaped sponge with flexible stem; height ~15 cm (Hestetun et al. 2017).	Hestetun et al. 2017
				***Asbestopluma* sp.**	Best et al. 2010, Fuller 2011

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
				Chondrocladia (Chondrocladia) grandis: Erect, club-shaped sponge; height 1–7 cm, width 2–4 mm (Hestetun et al. 2017).	Fuller 2011, Hestetun et al. 2017, V. Hayes pers. comm.
Sponges	Demospongiae	Poecilosclerida	Cladorhizidae	***Chondrocladia* spp.**: Erect, tough, straight stalked sponges with thin arms with inflated balloon-like tips; height 30 cm, width 10 cm (Best et al. 2010).	Best et al. 2010, V. Hayes pers. comm.
				Cladorhiza abyssicola: Note may include *C. gelida* (Hestetun et al. 2017). Erect, irregular branching sponge with central stem; height 15–30 cm (Hestetun et al. 2017, Dinn & Leys 2018).	Fuller 2011, Hestetun et al. 2017, Dinn & Leys 2018, V. Hayes pers. comm.
				Cladorhiza kenchingtonae: Erect, wire-like sponge, with few long thin branches; height <2 m (Hestetun et al. 2017).	Hestetun et al. 2017
				***Cladorhiza* spp.**: Erect, tree-like sponges; height <1 m (V. Hayes pers. comm.).	Best et al. 2010, V. Hayes pers. comm.
				Lycopodina versatilis: Small erect sponge with long stalk and cylindrical disk-like body; height 15$^+$ mm, width 10 mm (Hestetun et al. 2017).	Hestetun et al. 2017
			Coelosphaeridae	***Forcepia (Forcepia) thielei***: Thick, irregular shaped, possible leaf-like sponge with thick base; height 18 cm (Best et al. 2010; Tompkins et al. 2017).	Best et al. 2010, NAFO 2014; Tompkins et al. 2017
				***Forcepia* spp.**	Murillo et al. 2012, 2016b, Tompkins et al. 2017
				***Histodermella* sp.**: Small round sponge, with several thin projections; width 1–2 cm (Best et al. 2010).	Best et al. 2010, Fuller 2011
				Lissodendoryx complicata: Erect sponge with net-like branching and compressed branches; height 8–20 cm (Tompkins et al. 2017).	Tompkins et al. 2017, V. Hayes pers. comm.
Sponges	Demospongiae	Poecilosclerida	Crellidae	***Crella* spp.**: Encrusting sponges.	Murillo et al. 2012, 2016b

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
			Esperiopsidae	***Semisuberites* cf. *cribrosa***: Trumpet shaped sponge with long stalk and root-like holdfast; height 25 cm (Dinn 2019).	V. Hayes pers. comm.
				Esperiopsis villosa: Erect, massive and lobate sponge; height 6 cm, width 3 cm (Carter 1874).	Murillo et al. 2012, 2016b
			Hymedesmiidae	***Hymedesmia* sp.**: Thin encrusting sponge; height 1–2 mm, width 30 cm (Best et al. 2010).	Best et al. 2010
			Iotrochotidae	***Iotrochota* sp.**	Murillo et al. 2016b
			Isodictyidae	***Isodictya palmata***: Erect, digitate-like sponge with variably compressed branches; height 35 cm, width >20 cm (Picton et al. 2011).	Murillo et al. 2016b, V. Hayes pers. comm.
				***Isodictya* spp.**: Erect, arborescent sponges.	Fuller 2011
Sponges	Demospongiae	Poecilosclerida	Mycalidae	***Mycale (Mycale)* cf. *loveni***: Erect irregular fan shaped sponge with short firm pedicle; height ~30^{+} cm; width ~30^{+} cm (Fristedt 1887, V. Hayes pers. comm.).	Fuller 2011, Wareham-Hayes et al. 2017, Murillo et al. 2016b
				Mycale (Mycale) lingua: Soft massive lobed sponge, sometimes erect, very fragile; height 30 cm, width varies 10^{+} cm (Dinn & Leys 2018).	Best et al. 2010, Fuller 2011, Murillo et al. 2012, 2016b, Wareham-Hayes et al. 2017, Dinn & Leys 2018
			Myxillidae	***Melonanchora elliptica***: Encrusting sponge with tube-like projections; height <1 cm, width 3 cm (Dinn & Leys 2018).	Best et al. 2010, Fuller 2011, Dinn & Leys 2018
				***Melonanchora* sp.**	Murillo et al. 2016b

Group	Class	Order	Family	Taxa and associated morphologies	Distribution Sources
				***Myxilla* spp.**	Murillo et al. 2012, 2016b
			Tedaniidae	***Tedania (Tedania) suctorial***: Encrusting sponge with small erect projections; height <2 cm, width <5 cm (Dinn & Leys 2018).	Dinn & Leys 2018, V. Hayes pers. comm.
				***Tedania* sp.**	Murillo et al. 2016b
			Polymastiidae	***Polymastia andrica***: Cushion shaped sponge with long projections; height ~1 cm, width ~2 cm (Plotkin et al. 2018, Dinn & Leys 2018).	Murillo et al. 2016b, Plotkin et al. 2018, Dinn & Leys 2018, V. Hayes pers. comm.
				Polymastia boletiformis: Published as *Polymastia robusta*. Cushion shaped sponge with projections; height 10^{+} cm, width 10 cm (Picton 1998).	Fuller 2011, Plotkin et al. 2018, V. Hayes pers. comm.
				Polymastia corticate: Massive cushion shaped sponge with projections; height ~10 cm, width ~14 cm (Cárdenas & Rapp 2015).	Cárdenas & Rapp 2015, Murillo et al. 2016b
Sponges	Demospongiae	Poecilosclerida	Polymastiidae	***Polymastia grimaldii***: Large cushion shaped sponge, vertically compressed with many projections; height ~3 cm, width 5 cm (Plotkin et al. 2018, Dinn 2019).	Plotkin 2004, V. Hayes pers. comm.
				Polymastia hemisphaericum: Formerly *Radiella hemisphaericum*. Small cushion shaped sponge with projections; height ~1 cm, width ~4 cm (Plotkin et al. 2018).	Fuller 2011, Murillo et al. 2016b, Plotkin et al. 2018, V. Hayes pers. comm.
				Polymastia penicillus: Formerly *Polymastia mammillaris*. Cushion shaped sponge with projections; height 11 cm, 15 cm (Plotkin et al. 2018, ICES 2010)	Fuller 2011, Plotkin et al. 2018
				***Polymastia* spp.**: Cushion-shaped sponges with projections.	Best et al. 2010, Murillo et al. 2012, 2016b, NAFO 2014, Meredyk et al. 2020
				Polymastia thielei: Globular shaped sponge with projections; height ~ 3 cm, width 7 cm (Dinn & Leys 2018).	Plotkin et al. 2018, Murillo et al. 2016b, Dinn & Leys 2018, V. Hayes pers. comm.
				Polymastia uberrima: Cushion shaped sponge, ovoid to spherical with projections on the upper side; height ~1 cm, width 5 cm (Dinn & Leys 2018).	Fuller 2011, Murillo et al. 2016b, Plotkin et al. 2018, Dinn & Leys 2018, V. Hayes pers. comm.

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				Quasillina brevis: Bladder-like or club shaped sponge; height 5.5 cm, width 2.5 cm (Plotkin et al. 2018, Dinn & Leys 2018).	Best et al. 2010, Plotkin et al. 2018, Dinn & Leys, 2018
				Quasillina richardi	Murillo et al. 2016b
				Sphaerotylus* cf. *capitatus: Cushion shaped sponge with numerous projections of various sizes; height <10 cm, width ~16 cm (Dinn 2019).	V. Hayes pers. comm.
Sponges	Demospongiae	Polymastiida	Polymastiidae	***Spinularia sarsii***: Formerly *Radiella sarsii*. Flat, discoid sponge with a fringe of spicules along the periphery; height ~1 cm, width ~1 cm (Dinn and Leys 2018).	Plotkin et al. 2018, Dinn & Leys 2018, V. Hayes pers. comm.
				Tentorium semisuberites: Toadstool shaped sponge with a cylindrical body and a rounded top; height 4 cm, width 3 cm (Best et al. 2010).	Best et al. 2010, Fuller 2011, Murillo et al. 2012, 2016b, Plotkin et al. 2018, Dinn & Leys, 2018, V. Hayes pers. comm.
				Trachyteleia hispida: Cushion shaped sponge, hispid; height 2.5 cm, width 4 cm (ICES 2010).	Murillo et al. 2016b
				Weberella bursa: Compact globular sponge with short projections; height <10 cm, width <10 cm (Plotkin et al. 2018).	Fuller 2011, Murillo et al. 2012, 2016b, Plotkin et al. 2018, V. Hayes pers. comm.
		Suberitida	Halichondriidae	***Halichondriidae spp.**	Murillo et al. 2016b
				****Hymeniacidon* spp.**: Erect sponges; height <10 cm (Dinn & Leys 2018).	Murillo et al. 2012, *2016b, Dinn & Leys 2018
				Halichondria (Halichondria) panicea: Thickly encrusting sponge, sometimes erect and branching; height 1–20 cm (ICES 2010, Dinn & Leys 2018, ICES 2010).	Dinn & Leys 2018
			Stylocordylidae	***Stylocordyla borealis***: Erect bladder shaped sponge on a long thin stalk; height 10–30 cm, width ~2 cm (Hogg et al. 2010, Cárdenas & Rapp 2015).	Best et al. 2010, Beazley et al. 2013, Cárdenas & Rapp 2015, Murillo et al. 2016b
				***Stylocordyla* sp.**	Murillo et al. 2016b
Sponges	Demospongiae	Superitida	Suberitidae	***Suberitidae**	Murillo et al. 2016b
				***Homaxinella* sp.**: Erect, small tough finger-like or branching sponge with projections; width 10–15 cm (Best et al. 2010).	Best et al. 2010, NAFO 2014

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				***Rhizaxinella* sp.:** Long thin branching sponge with stalk and root-like support system; height 30 cm, width 1 cm (Best et al. 2010).	Best et al. 2010, Murillo et al. 2012, 2016b
				Suberites ficus: Thick lobed or cylindrical shaped sponge with smooth surface; height 40 cm, width 7 cm (Dinn 2019, Best et al. 2010).	Best et al. 2010, Fuller 2011, V. Hayes pers. comm.
				***Suberites* sp.**	Murillo et al. 2016b
				Homaxinella subdola: Synonym *Halichondria subdola*. Erect sponge with irregularly branching; height 22 cm, width 10 cm (Bowerbank 1866).	Fuller 2011
		Tethyida	-	**Hemiasterellidae sp.:** Erect, fan-shaped sponges.	Murillo et al. 2012
			Tethyidae	***Tethya* cf. *norvegica***: Massive spherical sponge; height <1 cm, width <1 cm (Dinn & Leys 2018). Possible identified as *T. aurantium* (J. Murillo pers. comm.).	Dinn & Leys 2018
		Tetractinellida	Ancorinidae	**Ancorinidae indet.**	Murillo et al. 2012
				Stelletta normani: Formerly *Dragmastra normani*. Massive subspherical sponge, very hispid; height 15^{+} cm, width 20^{+} cm (ICES 2009, Murillo et al. 2012, MSIP 2020).	Fuller 2011, Murillo et al. 2012, 2016b
Sponges	Demospongiae	Tetractinellida	Ancorinidae	***Stelletta tuberosa***: Note published as *Steletta* sp. (Murillo et al. 2012). Massive subspherical sponge; height ~15 cm, width ~15 cm (Cárdenas & Rapp 2015).	Murillo et al. 2012, 2016b, Cárdenas & Rapp 2015
				Stryphnus fortis: Note sister species to *S. ponderosus*. Often covered with *Hexadella detritifera*). Massive sponge, globular or lumpy shaped, surface extremely rough; height 50^{+} cm, width 15^{+} cm (Vosmaer 1885, Cárdenas & Rapp 2012, Fang et al. 2018).	Cárdenas & Rapp 2015, Murillo et al. 2012, 2016b
			Geodiidae	***Stryphnus ponderosus***: Note sister species to *S. fortis*. Often covered by *Desmacella annexa*. Massive irregular shaped sponge, lumpy, goblet or cup shaped; height ~30 cm, width 40 cm (ICES 2009, Best et al. 2010, MSIP 2020).	Best et al. 2010, Fuller et al. 2011, Cárdenas & Rapp 2015, V. Hayes pers. comm.

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				Geodia atlantica**:** Massive, subspherical sponge with deep funnel-like cavity; height 72 cm, width 40 cm (Cárdenas et al. 2013).	Cárdenas et al. 2013, Cárdenas & Rapp 2015
				Geodia barretti**:** Massive, spherical to subspherical sponge; height 20⁺ cm, width 80 cm (Cárdenas et al. 2013, Dinn & Leys 2018).	Fuller 2011, Murillo et al. 2012, 2016b, Cárdenas et al. 2013, Cárdenas & Rapp 2015, Dinn & Leys 2018
				Geodia macandrewi**:** Massive, subspherical sponge with somewhat flattened top; height ~30 cm (Cárdenas et al. 2013).	Fuller 2011, Murillo et al. 2012, 2016b, Cárdenas et al. 2013, Cárdenas & Rapp 2015, Dinn & Leys 2018
				Geodia nodastrella**:** Massive, spherical sponge; height 6 cm, width 6 cm (Cárdenas & Rapp 2015).	Cárdenas et al. 2013, Cárdenas & Rapp 2015
				Geodia parva**:** Massive, subspherical to cup-shaped sponge; height 26 cm, width 10⁺ cm (Cárdenas et al. 2013, Murillo et al. 2016b).	Cárdenas et al. 2013, Cárdenas & Rapp 2015, Murillo et al. 2016b
Sponges	Demospongiae	Tetractinellida	Geodiidae	***Geodia phlegraei*****:** Massive subspherical to cup-shaped sponge, can be somewhat flattened in large specimens; height 43 cm, width 20 cm (Cárdenas et al. 2013).	Fuller 2011, Murillo et al. 2012, Cárdenas et al. 2013, Cárdenas & Rapp 2015
				Geodia **spp.:** Massive, round or lobed shaped sponges (Best et al. 2010).	Best et al. 2010, Murillo et al. 2016, NAFO 2014, V. Hayes pers. comm.
			-	**Pachastrellidae spp.**	Murillo et al. 2016b
			Tetillidae	***Craniella cranium*****:** Also published as *Tetilla cranium*. Ball-shaped sponge, covered in small projections; height 10 cm, width ~5 cm (Best et al. 2010, Dinn & Leys 2018).	Best et al. 2010, Fuller 2011, Murillo et al. 2012, 2016b, Dinn & Leys 2018
				Craniella polyura**:** Elongated upright globular sponge; height ~7 cm (MSIP 2020).	Murillo et al. 2016
			Theneidae	***Thenea levis*****:** Massive, elongated subspherical sponge; height 2 cm, width 3–8 cm (Cárdenas & Rapp 2012). Note identified as *T. muricata* (Murillo et al. 2012).	Murillo et al. 2012, Cárdenas & Rapp 2012, 2015
	Hexactinellida	Tetractinellida	Theneidae	***Thenea muricata*****:** Massive subspherical sponge; height 1–20 cm, width 1–20 cm (Best et al. 2010). Misidentified, actually T. levis (Murillo et al. 2012).	Best et al. 2010, Fuller 2011, Murillo et al. 2012, 2016b, Cárdenas & Rapp 2012, 2015, Dinn & Leys 2018, V. Hayes pers. comm.
				Thenea **sp.**	Best et al. 2010, Murillo et al. 2016b

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				***Thenea valdiviae*:** Sub-circular or slightly flattened sponge; height 2 cm, width 2 cm (Cárdenas & Rapp, 2012).	Cárdenas & Rapp, 2012, 2015, Murillo et al. 2016b
Sponges	Hexactinellida	Verongiida	Ianthellidae	***Hexadella dedritifera*:** Formerly *Hexadella detritifera*; Encrusting sponge, commonly found on *Stryphus fortis* (Cárdenas & Rapp 2015).	Cárdenas & Rapp 2015
		Lyssancinosida	Euplectellidae	***Dictyaulus romani*:** Erect, tubular sponge; height 30 cm (Murillo et al. 2013).	Fuller 2008, Murillo et al. 2013, 2016b
				***Euplectella aspergillum*:** Erect cylinder sponge with delicate lattice-like casing; height 20 cm, width 5 cm (Owen 1841).	Fuller 2011
				***Euplectella* spp.:** Erect delicate cylinder, lattice-like casing; height 30 cm, width 15 cm (Best et al. 2010).	Best et al. 2010, Murillo et al. 2012, Meredyk et al. 2020, V. Hayes pers. comm.
			Rossellidae	***Asconema foliatum*:** Note alternate spelling *Asconema foliata*. Erect, thin-walled, multi funnel-shaped sponge; height 45 cm, width 36 cm (Dinn & Leys 2018).	Tabachnick & Menshenina 2007, Fuller et al. 2008, Best et al. 2010, Fuller 2011, Murillo et al. 2012, 2013, 2016b, Dinn & Leys 2018, V. Hayes pers. comm.
		Sceptrulophora	Aphrocallistidae	**Aphrocallistes beatrix:** Erect, thin-walled, irregular tube or funnel shaped sponge; height ~15 cm, width ~10 cm (Reiswig & Kelly 2011).	Fuller 2008, Fuller 2011, Murillo et al. 2013, 2016b
			Euretidae	**Chonelasma sp.:** Erect, vase-shaped sponge with flared edges; height 50 cm, width <100 cm (Best et al. 2010).	Best et al. 2010

Putative species (*); World Register of Marine Species (WoRMS); Marine Species Identification Portal (MSIP)