Lophelia reefs

MarLIN – Marine Life Information Network
Marine Evidence–based Sensitivity Assessment (MarESA) Review

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Section of *Lophelia pertusa* reef, Mingulay, Scotland.
Photographer: Murray Roberts
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- Core records
- Non-core, certain determination
- Non-core, uncertain determination
- Predicted habitat extent

17-09-2018
Biotope distribution data provided by
EMODnet Seabed Habitats
(www.emodnet-seabedhabitats.eu)

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Summary

≡ UK and Ireland classification

EUNIS 2008	A5.631	Circalittoral *Lophelia pertusa* reefs
JNCC 2015	SS.SBR.Crl.Lop	*Lophelia* reefs
JNCC 2004	SS.SBR.Crl.Lop	*Lophelia* reefs
1997 Biotope	COR.COR.Lop	Lophelia reefs

🏷 Description

The cold-water coral *Lophelia pertusa* forms patches of bushy growths composed of a network of anastomosing branches that grow into thickets, coppices and eventually reefs under favourable conditions. The morphology and size of reefs are highly variable but reefs may be circular, dome-shaped or elongate, forming distinct patches or arranged in lines of 'islands' along the edges of the

continental shelf, sea mounts, offshore banks and other raised sea bed features. Reefs may be composed of coral thickets 10 -50 m across and several metres high, mounds of 50 -500 m in diameter and 2 -33 m high, or through growth and/or fusion of nearby patches, form large elongate coral banks of up to 5 km in length and I km wide, reaching heights of ca 200 m and cover several square kilometres, depending on local conditions. Reefs of the scleractinian coral *Lophelia pertusa*, typically support a range of other biota. *Lophelia* reefs are generally found in areas of elevated current. The coral provides a 3 dimensional structure and a variety of microhabitats that provide shelter and a surface of attachment for other species. In the Sula Ridge Norway, the coral grows in an iceberg furrow forming a coral bank 13 km in length, 300 m wide and 45 m high. Although *Lophelia pertusa* dominates, other cold-water corals may also occur, e.g. *Madrepora oculata*, *Desmophyllum cristagalli*, *Dendrophyllia cornigera*, *Enallopsammia rostata* and *Solensmilia variabilis*. The reef supports a species rich assemblage of invertebrates, especially suspension feeders such as foraminiferans, sponges, hydroids, gorgonians (*Paragorgia arborea*, *Paramuricea placomus*, *Primnoa resedaeformis*). *Lophelia pertusa* may also support other corals (*Madrepora oculata* and *Solenosmilia variabilis*), polychaetes, bryozoans, brachiopods, asteroids, ophiuroids, holothurians, ascidians, squat lobsters (*Munida sarsi*) and bivalves may also be present. These organisms have all been recorded within and among the corals (Wilson, 1979; Mortensen *et al.*, 1995; Roberts *et al.*, 2009; Kazanidis *et al.*, 2016). Mobile species present include the redfish (*Sebastes viviparous* and *Sebastes marinus*), ling (*Molva molva*) and tusk (*Brosme brosme*) (Husebo *et al.*, 2002) and blackmouth catshark *Galeus melastomus* (Henry *et al.*, 2013). Relatively few species have so far been shown to be closely associated with live *Lophelia pertusa*, for example, eunicid polychaetes, especially *Eunice norvegica*, and brittlestars, especially *Ophiocantha* species. The associated community requires further study. The xenophyophore *Syringammina fragilissima* (a giant protozoan growing up to 20 cm in diameter) occurs at markedly increased densities in downstream 'tails' of the some *Lophelia* mounds (Masson *et al.*, 2003) . [**NB** biotope description composed by authors.]

↓ Depth range

50-100 m, 100-200 m

🏛 Additional information

The author is grateful to all the referees for their helpful comments and for highlighting additional information and recent findings.The sensitivity review uses information collated since 2005. The review of the ecology is based primarily on the detailed review of *Lophelia pertusa* by Rogers (1999) and may be updated in the future.

✔ Listed By

- none -

🔗 Further information sources

Search on:

G g G JNCC

Habitat review

⟳ Ecology

Ecological and functional relationships

Rogers (1999) stated that the ecology of *Lophelia pertusa* reefs was poorly understood and remained largely un-investigated. The following information is inferred from a few studies of the fauna of *Lophelia* reefs in nature and aquarium studies (Jensen & Frederiksen, 1992; Rogers, 1999; Mortensen, 2001). Although the major groups of organisms are probably similar, the exact species present will vary with location.

- *Lophelia pertusa* and other cold-water corals provide hard substrata for attachment of other epifaunal organisms, in the form of living and dead coral and coral fragments. The dense bushy growth of *Lophelia* locally modifies the environmental conditions (e.g. water flow) and provides a wide variety of niches for colonization by other species. Therefore, *Lophelia* may be regarded as an 'autogenic engineer' (Rogers, 1999) or key structural species.
- *Lophelia* is a passive suspension feeder or passive carnivore, which has been observed to take zooplankton such as calanoid copepods and cumaceans in nature, and to take live zooplankton such as chaetognaths, small crustaceans (ca 1 mm e.g. copepods), and larger species such as krill ca 2 cm in length in aquaria (Mortensen, 2001; Mortensen *et al.*, 2001). Mortensen (2001) demonstrated that *Lophelia* could also take a variety of foods, including dead food particles of krill, shrimp, herring and squid, and was able to reject unsuitable material including sediment. Mortensen (2001) concluded that *Lophelia* could utilize small organic particulates as food as well as live zooplankton. It probably also feeds on small invertebrates crawling over the coral surface.
- The hard substratum provided by *Lophelia*, together with the strong currents in the areas it occupies, favours suspension feeding invertebrates, e.g. foraminiferans, sponges, hydroids, gorgonians (soft corals), corals, polychaetes, bryozoans, brachiopods, asteroids, ophiuroids, holothurians, and ascidians. For example, brittlestars, especially *Ophiactis balli*, were observed sheltering within the empty cups (calices) of dead corals with only their arms protruding (Rogers, 1999).
- Mortensen (2001) suggested that there was a non-obligate mutualistic relationship between *Lophelia* and the polychaete *Eunice norvegica*, which shares a common distribution. In aquarium studies, *Eunice norvegica* was observed to steal food from the polyps of *Lophelia*, although Mortensen (2001) suggested that in nature *Lophelia* probably ingested live food before it could be stolen. *Eunice norvegica* was also observed to keep the coral surface clean of detritus and sedimentary particles, and in one instance attacked a sea urchin (*Cidaris cidaris*) that had climbed onto the coral. The polychaete may protect the coral from predators to some extent, a relationship seen in tropical coral communities (Mortensen, 2001). Most importantly, *Eunice norvegica* attaches its mucilaginous tube to the surface of the coral, which stimulates the coral to grow around and calcify the polychaetes' tube. This calcification may join adjoining coral branches, provide additional hard substrata for settlement of coral larvae and other invertebrates, and may strengthen the structure of the reef (Mortensen, 2001). In addition, tubes of the *Eunice norvegica* are capable of joining separate colonies, enhancing reef development, as seen in tropical corals (Dr Murray Roberts pers comm.).
- The tubes of *Eunice norvegica* may also support other species of polychaete, e.g. the scale worm *Harmothoe oculinarum*.

- Similarly, most bivalves were cavity dwellers occupying the empty calices of dead corals, e.g. *Hiatella arctica* and *Acar nodulosa*, while *Delectopecten vitreus* was found on the surface of live coral (Jensen & Frederiksen, 1992) and the giant file shell *Acesta excavata* may also use the coral as a substratum (Dr Jason Hall-Spencer pers comm.).
- Jensen & Frederiksen (1992) observed only a few gastropods, the most numerous of which was *Alvania jeffreysi*, a predator of foraminifera. However, several species of gastropod have been recorded from *Lophelia* reefs (see Rogers, 1999), many of which are probably epifaunal grazers.
- Many of the starfish and sea urchins recorded are probably epifaunal grazers and /or scavengers within the reef, while the mobile crustaceans including isopods, shrimp, crabs and hermit crabs are probably scavengers, or generalist predators of small invertebrates.
- The coral skeleton may be eroded by several groups of organisms, e.g. bacteria, fungi, and sponges (e.g. *Aka labyrinthica*, *Alectona millari* and *Cliona vastifera*) which bore into dead corals, while eunicid, cirratulid, sabellid and spionid polychaetes also bore into the coral skeleton. Rogers (1999) noted that bioeroders play an important role in the development and maturation of coral reefs. Bioeroders reduce the coral skeleton to sediment, and weakens the coral structure so that pieces of coral break off or fall over. However, cavities produced by bioeroders also provide additional habitat complexity. Rogers (1999) noted that bioerosion in shallow coral reefs leads to rates of reef destruction that are only slightly slower than the rates of reef growth, so that any factor that reduces the growth rate of the corals may result in loss of the reef, especially since only a single cold-water coral species dominates this biotope.
- Jensen & Frederiksen (1992) noted that many of the species they observed were only present as juveniles, suggesting that many species may use the *Lophelia* reef as a nursery area (Rogers, 1999).

Seasonal and longer term change

Lophelia reefs occupy relatively stable bodies of water (Rogers, 1999) but are still likely to experience seasonal fluctuations in current strength, temperature and food supply. The breaking of internal waves increases vertical mixing of the water column in areas of 'critical slope' (Frederiksen *et al.*, 1997), which may occur close to the shelf break around the Faeroes Islands and the Faeroe-Shetland Channel interface (Roberts *et al.*, 2003). Roberts & Anderson (2002a) noted that the polyps of *Lophelia* behaved asynchronously, without any clear diurnal patterns over a three day period in aquaria. Mortensen & Rapp (1998) detected distinct annual growth lines in *Lophelia*, and the growth of *Lophelia* from western Norway was carefully followed in aquaria over a 2.5 year period (Mortensen, 2001). Mortensen (2001) reported that linear extension of the skeleton was episodic, peaked in autumn, winter and spring, with a low growth period between June and September. In the aquaria, new polyps were generated mainly between August and December, the warmest part of the year, which suggested that temperature may be an important factor (Mortensen, 2001). However, deep-water population are probably not exposed to such temperature change. Mortensen (2001) observed no correlation between linear extension rates and temperature and salinity but concluded that the growth of the skeleton was correlated with seasonal variations in the abundance of particulate organic material and hence food availability.

The *Lophelia* reefs so far examined have been estimated to be extremely old, from several hundred to many thousands of years old. Therefore, although the longevity of individual coral polyps and associated species probably vary over time, the reef itself may be extremely long-lived (see 'time to reach maturity' below).

The associated fauna will probably exhibit seasonal fluctuations in abundance. For example, many bryozoan and hydroid species die back in the winter months. However, no other information was found.

Habitat structure and complexity

The shape and size of individual patches and reefs of *Lophelia* are highly variable, depending on local environmental conditions (Rogers, 1999). The density of branching varies and *Lophelia* may form robust 'bushes' in which the skeleton is thickened or finer more delicate branched colonies susceptible to damage e.g. from the pressure wave created by a submersible (Rogers, 1999). Reefs may be circular or 'halo-shaped', 'haystack-shaped', form domed mounds, or be elongated with one or more peaks, and the patches of reef may be arranged along the ridge of seamounts or banks in chains or 'islands groups' (Wilson, 1979a, b; Rogers, 1999; De Forges *et al.*, 2000; Mortensen *et al.*, 2001).

Wilson (1979b) suggested a model of *Lophelia* patch development, based on terms developed by Squires (1964), in which growth of an initial colony gives rise to coral fragments around it that either continue to grow or are colonized by *Lophelia* larvae. As the new colonies grow and merge they surround the central colony forming a 'thicket'. The central colony dies back, probably due to reduced water flow within the patch, and is reduced to coral debris, forming a halo shaped ring or 'coppice'. Subsequent phases of growth around the outside of the coppice results in concentric circles of growth forming a mature 'coppice' (see Wilson, 1979b for details). The reef becomes composed of several distinct zones, as exemplified by a *Lophelia* reef in the Stjernsund Fjord, Norway (Freiwald *et al.*, 1997; Rogers, 1999). The living coral at the top of the reef grows on top of large fragments of dead coral, underneath which was a layer of small fragments and sediment. The living coral on top of the reef formed ring-shaped colonies as described by Wilson (1979b). Coral fragments from the main reef had also fallen down only to grow as spherical colonies. Away from the main reef *Lophelia* formed isolated coral thickets and dead collapsed frameworks (Rogers, 1999).

In the Darwin Mounds of the Rockall Trough, Masson *et al.* (2003) suggested that the mounds had preceded reef formation. In their study, Masson *et al.* (2003) observed no stratification of coral fragments in cores of the mounds, the cores being composed of quartz sand rather than bioclastic sediment. They concluded that mounds were formed by the deposition of sediment on the surface of the seabed by fluid escapes from the seafloor, and subsequently colonized by *Lophelia* and its associated fauna. The mounds form a raised substratum, which is a preferred habitat for *Lophelia* and other suspension feeders (Masson *et al.*, 2003).

The network of living and dead coral branches provide niches for a variety of organisms, e.g. bivalves and brittlestars within dead coral cups, and eunicids within and between the branches of corals (see above). However, the majority of the fauna observed were within and on the dead coral and coral debris (Rogers, 1999). Some coral mounds form acoustically detectable 'tails' aligned with the prevailing current, e.g. in the Darwin Mounds 'tails' included high densities of the giant protozoan *Syringammina fragilissima* (Masson *et al.*, 2003).

Productivity

Frederiksen *et al.* (1997) suggested that *Lophelia* reefs on the continental slopes off Norway, west Scotland and the Faroes, occupy a depth at which tidal currents impinge on raised seabed features with a critical degree of slope to generate internal waves. The resultant mixing of the water column

above the shelf break generates nutrient rich surface waters, that in turn promotes phytoplankton productivity. Similarly, the increased mixing of bottom waters leads to resuspension of organic particulates from the seabed. Both effects can potentially increase the supply of food to *Lophelia* and other suspension feeders (Rogers, 1999). Rogers (1999) also noted that the massive reef complex on the Sula Ridge, off Norway was thought to rely on the supply of zooplankton from fertile surface waters. The occurrence of some *Lophelia* reefs in the vicinity of light hydrocarbon or methane seeps has led to the hypothesis that *Lophelia* reefs and their associated fauna may be supported by a chemosynthetic food chain (Hovland & Thomsen, 1997; Hovland, *et al.*, 1998). But Rogers (1999) concluded that the evidence was equivocal. For example, occurrences of *Lophelia* in the Rockall Bank and elsewhere are not associated with hydrocarbon seeps (Rogers, 1999). Analysis of stable radiocarbon isotope (^{13}C) levels in the skeleton of *Lophelia pertusa* and ^{13}C/^{12}C ratios in tissue is not consistent with a food chain based on hydrocarbon seeps (see Rogers, 1999 and Roberts *et al.*, 2003 for discussion). Rogers (1999) suggested that most of the hydrocarbons are utilized by other organisms at the sediment-water interface.

Although, the only living part of the *Lophelia* framework are the surface colonies, the skeletal framework provides substratum, interstices, refugia and feeding grounds for a wide variety of other organisms. Most of the biomass of the reef is provided by the associated fauna, especially in smaller reefs (Rogers pers comm.). Overall, *Lophelia* reefs are probably highly productive ecosystems (secondary productivity) but no direct information was found. *Lophelia* reefs probably exhibit tight coupling between the pelagic and benthic ecosystems (Dr Murray Roberts, pers comm.).

Recruitment processes

Colonies of *Lophelia* grow by intratentacular budding, the division of an existing polyp into two polyps (Cairns, 1979; Rogers, 1999). In addition, *Lophelia* may generate new colonies by fragmentation, whereby coral fragments fall or are broken off, and continue to grow under suitable conditions. Fragmentation is a major mechanism whereby the initial colony expands to form a coppice and ultimately a reef (see 'habitat complexity' above and Wilson, 1979b). Some corals can reproduce by parthenogenesis, the development of an un-fertilized egg, while others exhibit 'polyp bailout' in which a polyp or piece of coral tissue leaves its skeleton, and moves to a suitable substratum and secretes a new skeleton (Richmond, 1997). However, there is currently no evidence for the existence of parthenogenesis or 'polyp bailout' in *Lophelia* (Rogers, 1999).

Lophelia pertusa is gonochoristic and is thought to spawn annually (Waller, 2005). Evidence from the North East Atlantic *Lophelia pertusa* supports this supposition, and samples collected within this area showed a seasonal reproductive cycle with a single cohort per year, with a spawning event around February (Waller & Tyler 2005). Asexual replication of *Lophelia pertusa* polyps occurs by unequal intratentacular budding (Cairns 1979, 1994; Roberts et al., 2009; Brooke & Jarnegren, 2013). Larsson *et al.* (2014) examined embryogensis and larval development in the laboratory in fragments of live *Lophelia pertusa* colonies from the Tisler reef and Trondheim Fjord, Norway. Spawning occurred in Jan to March, althought spawning was asynchronous depending on site of origin, over a period of two months. They observed that mutliple male polyps spawned simultaneously, resulting in a high fertilization efficiency. Spawned occytes were 160 µm in diameter and resultant embryos were neutral or negatively buoyant and developed into 120-270 µm long ciliated planulae. The planulae were active swimmers (0.5 mm/s) and actively swam upwards into the upper water column. Larsson *et al.* (2014) estimated that larvae could vertically migrate ca 50 m/day, which would bring them out of the benthic boundary layer in reef conditions. The planulae spent three to five weeks in the water column before the onset of bottom-probing

behaviour. Larsson *et al.* (2014) concluded that the larvae were probably planktotrophic rather than lecithotrophic suggested by Waller (2005). Bottom-probing behaviour became common amongst the larvae studied four to five weeks after fertilization and coincided with the development of nematocysts, which suggested that had become competent, although settlement was not observed. The planula larvae of *Lophelia pertusa* require hard substrata for settlement, including rock surfaces, artificial substrata, coral fragments or hydrocarbon seep associated carbonates. In sedimentary areas, *Lophelia pertusa* may settle on hard substrata as small as a shell, pebble, or worm tube (Rogers, 1999). However, a hard substratum is a pre-requisite for settlement and a layer of sediment may interfere with settlement and hence recruitment.

The ability of *Lophelia pertusa* to colonize isolated hard substrata and artificial substrata such as submarine cables, the Brent Spar storage buoy and oil rigs suggests that it has a pelagic larval phase (Rogers, 1999; Roberts, 2002a). Roberts (2002a) concluded that the occurrence of *Lophelia* on structures in the Beryl and Brent oil fields in the North Sea was good evidence for a dispersive planula larva. Roberts (2002a) suggested that the colonies in the North Sea oil fields originated as larvae from the offshore banks of the Atlantic margin, and were carried into the North Sea in cooled Atlantic water, possibly via the east Shetland Atlantic Inflow current. Transport of larvae in the water mass of prevailing water currents probably provides the opportunity for long distance dispersal. Larsson *et al.*'s (2014) study corroborates these assumptions. Larsson *et al.* (2014) noted that the ability of the larvae to swim upwards would put them into the tidal currents flowing over reefs (ca 0.1-0.4 m/s) so that they were likely to be swept away and unlikely to settle in their native reef, although they cite a genetic study that indicated that larval retention occurred in reefs in the NE Skagerrak (Dahl *et al.*, 2012; cited in Larsson *et al.*, 2014). Larsson *et al.* (2014) also recorded a larval lifespan of eight weeks (but noted it might be longer in the wild), which when combined with the late onset of competnency, suggested a high dispersal potential.

Evidence suggests that larvae are dispersive but that migration is not sufficient to counteract reproductive isolation of populations (Dr Alex Rogers, 2005 pers comm.). Molecular genetic data indicates that Beryl oil fields samples of *Lophelia* are closely related to northern Rockall Trough populations but that there is strong genetic differentiation (population sub-division), with very low gene flow between areas (Le Goff-Vitry & Rogers, 2002; Dr Alex Rogers, 2005 pers comm.). Molecular genetic studies of the population of *Lophelia pertusa* in the North East Atlantic showed that it was not a panmictic popualtion but composed of genetically distinct offshore and fjordic subpopulations from the Iberian margin to the Scandinavian fjords (Le Goff-Vitry & Rogers, 2005). Also, inbreeding was also observed in some subpopulations that indicated self-recruitment in those sites. In addition, there was high variation in the degree of genetic variation between subpopulations, for example in the Darwin mounds that exhibited a high proprotion of clones and low genetic diversity. In particular, the fjordic populations were highly differentiated genetically, for example, the Osterfjord subpopulation showed very low genetic diversity. Morrison *et al.* (2011; summary only) also found genetic differentiation between populations of *Lophelia pertusa* in the Gulf of Mexico, coastal souteast United States, New England seamounts and the eastern North Atlantic. They concluded that while some larvae were dispersed over large geographic distances gene flow between the oceans regions was restricted. The evidence suggests that asexual reproduction predominates in reef growth and that the contribution from larvae may be limited (Dr Alex Rogers, 2005 pers comm.). Le Goff-Vitry & Rogers (2002, 2005) concluded that gene flow along the continental margin was sporadic and that recolonzation of disturbed coral reefs through larval dispersal is likely to take long periods of time.

The associated epifauna and interstitial fauna probably depend on locality and recruit from the surrounding area. Many hydroids, ascidians and probably sponges have short lived planktonic or

demersal larvae with relatively poor dispersal capabilities. Exceptions include *Alcyonium digitatum* and hydroids that produce medusoid life stages and probably exhibit relatively good dispersal potential. Hydroids are opportunistic, fast growing species, with relatively widespread distributions, which colonize rapidly and are often the first groups on species to occur on settlement panels. Sponges may take longer to recruit to the habitat but are good competitors for space. Recruitment in epifaunal communities is discussed in detail in the faunal turf biotopes MCR.Flu, CR.Bug and in *Modiolus modiolus* beds (MCR.ModT). Mobile epifaunal species, such as echinoderms (starfish and brittlestars), crustaceans, and fish are fairly vagile and capable of colonizing the community by migration from the surrounding areas. In addition, most echinoderms and crustaceans have long-lived planktonic larvae with potentially high dispersal potential, although, recruitment may be sporadic, especially in echinoderms.

Time for community to reach maturity

Mortensen *et al.* (2001) suggested that the size of *Lophelia* reefs was determined by the time taken for development and the topography of the seabed that affects both the area over which coral fragments and rubble can spread and the local currents and hence, food supply and growth rates.

The growth rate of *Lophelia* is very slow. Estimates of growth rate range from 2 to 25 mm/yr. depending on location (Wilson, 1979b; Rogers, 1999; Hall-Spencer *et al.*, 2002; Roberts, 2002a) although inaccurate sampling of the coral skeleton may have led to biased estimates. Studies of growth lines suggested a mean extension rate of 5.5 mm/yr., with linear extension rates greatest in the early stages of polyp growth, slowing with age (Mortensen & Rapp, 1998). Measurement of linear extension rates in aquarium specimens gave a mean annual growth rate of 9.4 mm/yr. (Mortensen, 2001). Rates of growth on artificial structures were estimated to range from 6 mm/yr. on submarine cables in north west Spain to 26 mm/yr. on the Brent Spar storage buoy (Bell & Smith, 1999; Roberts, 2002a).

Estimates of potential age of *Lophelia* colonies and reefs vary with location and with the growth rates estimates used to calculate age. For example, Wilson (1979b) estimated that a single colony 1.5 m in height would probably be 200 -366 years old (based on a growth rates between 7.5 and 4.1 mm/yr. respectively). *Lophelia* reefs sampled off Norway, 25 m in height and 330 x 120 m in area were probably between 1,000 and 6,250 years old, depending on growth rate (Rogers, 1999). Radiocarbon dating of cold-water corals from west Ireland, provided estimated ages of 451 years before present (BP) for live *Lophelia pertusa* and 762 years BP for dead *Lophelia pertusa* fragments (Hall-Spencer *et al.*, 2002). However, dead coral rubble formed by the cold-water coral *Desmophyllum cristagalli*, at the same site, were between 4067 and 5001 years BP, which suggested that the reef system was probably at least 4,500 years old (Hall-Spencer *et al.*, 2002). The age of *Lophelia* reefs in south east Norway and west of Fedje Island, west Norway was estimated to be 8,700 and 3,600 years BP respectively (Mikkelsen *et al.*, 1982; Rokoengen & Østma, 1985; Mortensen *et al.*, 2001). The *Lophelia* reefs of the Sula Ridge were estimated to be 8,600 years old, having developed over the last 10,000 years since the last ice age (Hovland & Mortensen, 1999; Mortensen *et al.*, 2001). Coral rubble from cold-water coral reefs on the Florida Hatteras slope, which was not ice covered, had an age of ca 20,230±230 years BP (Mortensen *et al.*, 2001).

Recruitment to available hard substrata by epifauna such as hydroids, and ascidians is probably fairly rapid (see MCR.Flu or CR.Bug), with sponges and soft corals taking longer to develop. Bryozoans, hydroids, and ascidians are opportunistic, grow and colonize space rapidly and will probably develop a epifaunal cover within 1-2 years (for example see Sebens, 1985, 1986). Mobile epifauna and infauna will probably colonize rapidly from the surrounding area. Slow growing

species such as some sponges and anemones (see Sebens, 1985, 1986), will probably take many years to develop significant cover, so that a diverse community may take up to 5 -10 years to develop, depending on local conditions.

While, epifaunal and infaunal species would colonize relatively rapidly, the key species determining the development of the reef is *Lophelia* itself. Deep-sea communities are thought to have very slow colonization rates (Rogers, 1999). While *Lophelia* may have a dispersive larval stage (see Roberts, 2002a), there is little information available on recruitment rates in natural systems. However, recent molecular genetic data suggests that larval recruitment is probably low or sporadic (Le Goff-Vitry & Rogers, 2002, summary only; Dr Alex Rogers, pers comm.). Overall, even with good recruitment, *Lophelia* is very slow growing and would probably take several hundred years to develop large colonies (ca 1.5-2 m in diameter) and several thousand years to develop a reef system 10 -30 m thick (Fosså *et al.*, 2002).

Additional information

None entered.

🖼 Preferences & Distribution

Habitat preferences

Depth Range	50-100 m, 100-200 m
Water clarity preferences	No information found
Limiting Nutrients	No information found
Salinity preferences	Full (30-40 psu)
Physiographic preferences	Open coast
Biological zone preferences	Lower circalittoral
Substratum/habitat preferences	Artificial (man-made), Bedrock, Features / other, Fine clean sand, Hard (immobile), Hard (mobile), Pebbles
Tidal strength preferences	Moderately Strong 1 to 3 knots (0.5-1.5 m/sec.), Weak < 1 knot (<0.5 m/sec.)
Wave exposure preferences	Extremely sheltered
Other preferences	Oceanic water

Additional Information

Distribution
Lophelia pertusa has been recorded globally from the North Atlantic, parts of the Mediterranean, along the coasts of west Africa, the United States, east Canada and around the mid Atlantic islands south to Tristan da Cunha. It is also recorded from the Pacific, southern California, Cobb Seamount, and from the Island of St Paul in the Indian Ocean. There is also a single record from the Macquarie Ridge, south of New Zealand (Rogers, 1999). However, records often refer to dead or subfossil remains, may not represent reefs in all cases, and *Lophelia* often occurs as isolated patches over large areas of seabed, making it difficult to detect. Therefore, its living distribution may be inaccurate (Rogers, 1999). Recent genetic evidence suggests that Brazilian records of *Lophelia* are genetically distinct and may represent a different species or sub-species (Le Goff-Vitry *et al.*, in press; Dr Alex Rogers, pers comm.).

Lophelia pertusa has been recorded from the continental shelf of the north east Atlantic more frequently than any other place in the world (Rogers, 1999). In addition, to records in British and Irish waters, *Lophelia* reefs have also been recorded from Norwegian fjords, and on raised offshore seabed features from Haltenbanke, Froyabanken and the Sula Ridge in south and west Norway, the Faroes shelf, and from the Porcupine Basin south along the continental shelf edge to North Africa (Rogers, 1999; ICES, 2002; Roberts, 2002b; A. Grehan pers. comm.). Scattered records also occur in the North Sea, the Outer Hebrides, Stanton Bank, and Donegal Basin (Rogers, 1999; Roberts *et al.*, 2003). A review of the distribution of cold water coral in European waters is provided by Zibrowius (1980) and a detailed list of records is presented by Rogers (1999).

Habitat preferences

- *Lophelia pertusa* requires hard substrata (e.g. rock, coral fragments, artificial substrata, or hydrocarbon seep associated carbonates) on which to settle. Colonies that occur in sedimentary habitats have settled on small pieces of hard substrata such as pebbles, shells or worm tubes (Rogers, 1999).
- *Lophelia pertusa* appears to prefer the presence of oceanic waters. For example, *Lophelia* only occurs in Norwegian fjords that allow deep oceanic water into the fjord; its upper limit determined by the depth of coastal waters (Rogers, 1999).
- Its preference for oceanic waters suggested that *Lophelia* was sensitive to salinity and temperature (Rogers, 1999). *Lophelia pertusa* is found in water between 4 and 12 °C (Rogers, 1999) but records from the Mediterranean suggest it can survive up to 13 °C (Mortensen, 2001). Rogers (1999) noted that *Lophelia* is not usually found in waters colder than 6 °C but that it may encounter lower temperatures at the lower limits of its depth range. In a recent study, Roberts *et al.* (2003) noted a strong correlation between the occurrence of *Lophelia* and temperature. With a single exception, *Lophelia* had not been recorded in waters colder than 4 °C and was absent from depths of greater than 500 m in the Faeroe-Shetland Channel, presumably due to the influence of cold Nordic waters (e.g. the Arctic Intermediate Water and/or Norwegian Sea Arctic Water with temperatures of 1 -5 °C or -0.5 to 0.5 °C respectively) (Roberts *et al.*, 2003). The only record of *Lophelia* in the Faeroe-Shetland Channel below 500 m occurred in an area subject to temperatures below 4 °C for 52% of a 10 month period of observations and below zero for 4% of the same period (Bett, 2000). Roberts *et al.* (2003) suggested that the above record probably represented the limit of *Lophelia pertusa*'s range but that present evidence suggested that seabed mounds associated with coral growth were unlikely at depths influenced by cold Nordic waters.
- *Lophelia pertusa* occurs in waters of 35 -37 psu but in fjords tolerates salinities as low as 32 psu (Rogers, 1999; Mortensen *et al.*, 2001).
- The upper limit of *Lophelia* in fjords corresponds to the position of the thermocline (Rogers, 1999). However, Frederiksen *et al.* (1992) considered the origin of the water masses to be more important, while Mortensen *et al.* (2001) suggested that the pycnocline between lower salinity, warmer coastal waters and deeper, cooler oceanic water resulted in more stable conditions within the fjords, and a strong influx of oceanic waters.
- The upper limit of *Lophelia* in oceanic waters is probably seen on oil platforms in the North Sea. *Lophelia pertusa* was reported growing on single point moorings of the Beryl Alpha platform between depths of 75 and114 m (Roberts, 2002a). The water column around the platform was stratified; the salinity varied from 34.8 ppt at the surface to just over 35 ppt at 50 m, while the surface temperature remained fairly constant at 11.5 °C to a depth of 50 m before dropping rapidly to 8 °C between 70 and 110 m (Roberts, 2002a). Roberts (2002a) noted that the depth of *Lophelia* corresponded with 8 °C and a salinity of 35 ppt.

He suggested that *Lophelia* was restricted to depths of greater than 70 m by the physical conditions, competition from other epifauna (e.g. sponges and sea anemones) and possibly by wave action during storms (Roberts, 2002a).

- Strong current flow appears to be required for growth in *Lophelia*, which occurs in areas of strong water flow. *Lophelia* reefs occur where the topography causes current acceleration, e.g. on raised seabed features such as seamounts and banks and where the channel narrows in Norwegian fjords (Rogers, 1999). For example, soft corals were reported to reach higher densities near the peaks of seamounts rather than the slopes, or along the edges of wide peaks (see Rogers, 1999). Frederiksen *et al.* (1992) suggested that topographical highs create internal waves, depending on slope, that resuspended organic particulates from the seabed, and increase the flux of nutrient-rich waters to the surface waters increasing phytoplankton productivity; both effects resulting in increased food availability for *Lophelia* and other suspension feeders.

- Water flow is important for suspension feeders and passive carnivores, such as *Lophelia*, to provide adequate food, oxygen and nutrients, to remove waste products and prevent sedimentation, however, the optimum current speed varies with species (see Hiscock, 1983 for discussion). For example, Mortensen (2001) observed no polyp mortality in the vicinity of his aquaria inlets but high mortality at the opposite end. Similarly, the death of coral polyps within a coral coppice is thought to be due to reduced water flow within the colony (Wilson 1979b). Mortensen (2001) also noted that high current flow (greater than ca 0.05 m/s) was detrimental to growth, presumably due to reduced food capture rates. Frederiksen *et al.* (1992) suggested that *Lophelia* reefs around the Lousy and Hatton Banks would typically encounter currents speeds of 0.01 -0.1 m/s. Water flow rates >0.4 m/s were recorded by moored and landed deployed current meters close to deep-water coral mounds in the Porcupine Seabight (White , 2001 cited in Grehan *et al.*, 2003), while Masson *et al.* (2003) recorded a maximum residual bottom water flow of 0.35 m/s over a 20 day period in July 2000 over the Darwin Mounds. Food availability may be of greater importance than current speed alone.

- Around the Norwegian /Scottish Shelf and Faroes, *Lophelia* most commonly occurs at depths between 200 -400 m, and between 200 -1000 m in the Massifs off west Ireland and the Bay of Biscay, and in some records extends to 3000 m (Rogers, 1999). Rogers (1999) suggested that its deepest limit may coincide with the oxygen minimum zone.

- In deep waters the upper limit of *Lophelia* is probably controlled by the transition from oceanic to coastal or surface waters (see Rogers, 1999). However, *Lophelia* reefs occur as shallow as 50 m in Norwegian fjords. Frederiksen *et al.* (1992) suggest that its upper limit is controlled by wave action. Draper (1967) noted that wave periods in offshore areas are generally of longer than in enclosed seas and therefore penetrate to greater depths. However, Draper (1967) estimated that as far out as the continental shelf, for one day a year, storm conditions could generate a oscillatory water movement on the seabed of only ca 0.4 m/s at 180 m. Wave mediated currents are oscillatory and possibly more likely to result in damage to rigid corals than water flow (see Hiscock, 1983), although their skeletons are quite robust (Dr Jason Hall-Spencer pers comm.). In Norwegian fjords where *Lophelia* reefs occur as shallow as 50 m, wave action is slight at the surface and most likely does not penetrate more than a few tens of metres. Inner fjords have limited fetch so that wave action is unlikely to penetrate to more than a few tens of metres even in storm conditions (Dr Keith Hiscock pers. comm.). Rogers (1999) noted that the upper limit of *Lophelia* in the Norwegian fjords also coincided with the thermocline, and that the turbidity of the coastal surface water also reduced competition from algae.

- It has been suggested that *Lophelia* reefs are associated with hydrocarbon or methane seeps (Hovland & Thomsen, 1997; Hovland, *et al.*, 1998). But Rogers (1999) concluded

that the evidence was equivocal. For example, occurrences of *Lophelia* in the Rockall Bank and elsewhere are not associated with hydrocarbon seeps (Rogers, 1999). Analysis of stable radiocarbon isotope (^{13}C) levels in the skeleton of *Lophelia pertusa* and ^{13}C/^{12}C ratios in tissue is not consistent with a food chain based on hydrocarbon seeps (see Rogers, 1999 and Roberts *et al.*, 2003 for discussion). Rogers (1999) suggested that most of the hydrocarbons are utilized by other organisms at the sediment-water interface. However, in some locations the hydrocarbon seep associated carbonates may provide hard substrata for settlement in an otherwise sedimentary habitat.

Overall, *Lophelia* reefs require hard substrata, the presence strong currents and a good food supply, usually associated with raised seabed features, banks and sea mounts. *Lophelia* occupies a relatively narrow range of temperatures (stenothermal) and salinity (stenohaline), although its upper limit may be determined by a number of factors.

✤ Species composition

Species found especially in this biotope

- *Eunice norvegica*
- *Lophelia pertusa*

Rare or scarce species associated with this biotope

-

Additional information

Rogers (1999) collated species lists from all previous studies of *Lophelia* reefs in the north-east Atlantic and noted that about 886 species had been recorded, although this number of species is probably an under-estimate. Diverse species groups include the Foraminifera, Polychaeta, Echinodermata, and Bryozoa. The diversity of polychaetes, echinoderms and bryozoans recorded from *Lophelia* reefs is similar to that found on shallow water tropical coral reefs (Rogers, 1999). However, Scleractina (corals), Mollusca and Pisces (fish) have relatively low diversities compared to tropical reefs (see Rogers, 1999). Jensen & Frederiksen (1992) suggested that most species present were not strongly associated or endemic to the *Lophelia* reefs they studied, however the associated community is still poorly understood (Rogers, 1999). Recent studies of the fauna of coral-water coral reefs on seamounts off Tasmania by Koslow *et al.* (2001) recorded 262 species of invertebrates of which 24 -43% were new to science and 16 -33% were restricted to the seamount environment, while De Forges *et al.* (2000) recorded 850 species of mega and macrofauna of which 29 -34% were new to science and were potential seamount endemics. Overall, cold water coral reefs represent biodiversity hot spots within their area. For example, Masson *et al.* (2003) reported that initial studies suggested that invertebrate density was about 2-3 times higher on the Darwin Mounds than the surrounding sediments. Further study is required to estimate the biodiversity of northeast Atlantic *Lophelia* reefs and seamounts.

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

Lophelia pertusa is the only characterizing species within SS.SBR.Crl.Lop. *Lophelia pertusa* is the most common reef forming scleractinian cold-water coral. *Lophelia pertusa* colonies can grow to several metres, and branches of separate colonies can anatomise, strengthening the structure of the reef (Roberts *et al.*, 2009). The complex reef formations that are created by *Lophelia pertusa* provide a range of niches, which host a wide number of species (Buhl & Mortensen *et al.*, 2005; Mortensen *et al.*, 2010; Freiwald *et al.*, 2004; Muller *et al.*, 2013). A total of 1317 species have been listed associated with *Lophelia pertusa* reefs within the North East Atlantic (Roberts *et al.*, 2006). Therefore, although there is not a full species list associated with this biotope, it is likely that it will have high species diversity. Henry & Roberts (2007) found that the biodiversity of cold-water coral mounds containing *Lophelia pertusa* in the North East Atlantic was typically greater than that of the off-mound habitats. Jonsson *et al.* (2004) also found that there was a decrease in the biodiversity and the abundance of individuals the further from a *Lophelia pertusa* reef within a Swedish fjord. The increase in biodiversity around *Lophelia pertusa* reefs shows that they are important ecosystem engineers. Therefore, while *Lophelia pertusa* is not the only coral species found in the cold-water coral reefs of the North East Atlantic, it is the major reef forming species and, hence the focus for sensitivity assessment.

Resilience and recovery rates of habitat

Lophelia pertusa has a worldwide distribution. However, records show it to be most abundant in deep waters, at high latitudes in the North East Atlantic (Davies *et al.*, 2008). Global oceanographic data show that *Lophelia pertusa* is found at a mean depth of 480 m (Davies *et al.*, 2008). Most records were found where current speeds (mean of 0.07 m/s) and productivity (mean of 0.9 mg/m3) are higher than the regional mean, at full salinity (35), and where mean temperatures were 6.2-6.7°C and mean dissolved oxygen levels were 6.0-6.2 ml/l (Davies *et al.*, 2008). Until the 1990's little scientific information was available on *Lophelia pertusa* (Wilson, 1979a,b; Rogers, 1999). However, the rapid growth in commercial deep-water activities such as bottom trawling and offshore hydrocarbon exploration meant that greater understanding of deep-water ecosystems was needed. Although there is extensive literature on the destruction of cold-water coral reefs through anthropogenic pressures, there is almost no information regarding the recovery of these habitats.

The oldest radiocarbon dated *Lophelia pertusa* colony was found off the coast of Norway and was between 7800 – 8800 years old (Mikkelson *et al.*, 1982; Hovland *et al.*, 1998; Hovland & Mortensen, 1999). *Lophelia pertusa* caught as by-catch from the west coast of Ireland was found to be at least 4550 years old (Hall-Spencer *et al.*, 2002). In the high latitudes in the North East Atlantic, the growth of *Lophelia pertusa* reefs is unlikely before 10,000 years ago, due to the extent of ice during the last ice age (Schröder-Ritzrau, 2005). The growth of *Lophelia pertusa* varies. The lowest recorded growth rate was 5 mm / annum (Roberts, 2002a) with the highest being 34 mm/ annum (Gass & Roberts, 2006).

Lophelia pertusa is gonochoristic and is thought to spawn annually (Waller, 2005). Evidence from the North East Atlantic *Lophelia pertusa* supports this supposition, and samples collected within this area showed a seasonal reproductive cycle with a single cohort per year, with a spawning event around February (Waller & Tyler 2005). Asexual replication of *Lophelia pertusa* polyps occurs by unequal intratentacular budding (Cairns 1979, 1994; Roberts et al., 2009; Brooke &

Jarnegren, 2013). Larsson *et al.* (2014) examined embryogenesis and larval development in the laboratory in fragments of live *Lophelia pertusa* colonies from the Tisler reef and Trondheim Fjord, Norway. Spawning occurred in Jan to March, although spawning was asynchronous depending on site of origin, over a period of two months. They observed that multiple male polyps spawned simultaneously, resulting in a high fertilization efficiency. Spawned oocytes were 160 μm in diameter and resultant embryos were neutral or negatively buoyant and developed into 120-270 μm long ciliated planulae. The planulae were active swimmers (0.5 mm/s) and actively swam upwards into the upper water column. Larsson *et al.* (2014) estimated that larvae could vertically migrate ca 50 m/day, which would bring them out of the benthic boundary layer in reef conditions. The planulae spent three to five weeks in the water column before the onset of bottom-probing behaviour. Larsson *et al.* (2014) concluded that the larvae were probably planktotrophic rather than lecithotrophic suggested by Waller (2005). Bottom-probing behaviour became common amongst the larvae studied four to five weeks after fertilization and coincided with the development of nematocysts, which suggested that had become competent, although settlement was not observed. The planula larvae of *Lophelia pertusa* require hard substrata for settlement, including rock surfaces, artificial substrata, coral fragments or hydrocarbon seep associated carbonates. In sedimentary areas, *Lophelia pertusa* may settle on hard substrata as small as a shell, pebble, or worm tube (Rogers, 1999). However, a hard substratum is a pre-requisite for settlement and a layer of sediment may interfere with settlement and hence recruitment.

The ability of *Lophelia pertusa* to colonize isolated hard substrata and artificial substrata such as submarine cables, the Brent Spar storage buoy and oil rigs suggests that it has a pelagic larval phase (Rogers, 1999; Roberts, 2002a). Roberts (2002a) concluded that the occurrence of *Lophelia* on structures in the Beryl and Brent oil fields in the North Sea was good evidence for a dispersive planula larva. Roberts (2002a) suggested that the colonies in the North Sea oil fields originated as larvae from the offshore banks of the Atlantic margin, and were carried into the North Sea in cooled Atlantic water, possibly via the east Shetland Atlantic Inflow current. Transport of larvae in the water mass of prevailing water currents probably provides the opportunity for long-distance dispersal. Larsson et al.'s (2014) study corroborates these assumptions. Larsson *et al.* (2014) noted that the ability of the larvae to swim upwards would put them into the tidal currents flowing over reefs (ca 0.1-0.4 m/s) so that they were likely to be swept away and unlikely to settle in their native reef, although they cite a genetic study that indicated that larval retention occurred in reefs in the NE Skagerrak (Dahl *et al.*, 2012; cited in Larsson *et al.*, 2014). Larsson *et al.* (2014) also recorded a larval lifespan of eight weeks (but noted it might be longer in the wild), which when combined with the late onset of competency, suggested a high dispersal potential.

Evidence suggests that larvae are dispersive but that migration is not sufficient to counteract reproductive isolation of populations (Dr Alex Rogers, 2005 pers comm.). Molecular genetic data indicates that Beryl oil fields samples of *Lophelia* are closely related to northern Rockall Trough populations but that there is strong genetic differentiation (population sub-division), with very low gene flow between areas (Le Goff-Vitry & Rogers, 2002; Dr Alex Rogers, 2005 pers comm.). Molecular genetic studies of the population of *Lophelia pertusa* in the North East Atlantic showed that it was not a panmictic population but composed of genetically distinct offshore and fjordic subpopulations from the Iberian margin to the Scandinavian fjords (Le Goff-Vitry & Rogers, 2005). Also, inbreeding was also observed in some subpopulations that indicated self-recruitment in those sites. In addition, there was high variation in the degree of genetic variation between subpopulations, for example in the Darwin mounds that exhibited a high proportion of clones and low genetic diversity. In particular, the fjordic populations were highly differentiated genetically, for example, the Osterfjord subpopulation showed very low genetic diversity. Morrison *et al.* (2011; summary only) also found genetic differentiation between populations of *Lophelia pertusa* in

the Gulf of Mexico, coastal southeast United States, New England seamounts and the eastern North Atlantic. They concluded that while some larvae were dispersed over large geographic distances gene flow between the ocean regions was restricted. The evidence suggests that asexual reproduction predominates in reef growth and that the contribution from larvae may be limited (Dr Alex Rogers, 2005 pers comm.). Le Goff-Vitry & Rogers (2002, 2005) concluded that gene flow along the continental margin was sporadic and that recolonization of disturbed coral reefs through larval dispersal is likely to take long periods of time.

Fragmentation of the coral skeleton is part of the process of reef growth and development (Wilson, 1979b; Rogers, 1999). Therefore, minor damage to colonies is probably a natural process within reef formation. *Lophelia pertusa* larvae have to settle onto hard substrata, yet the reefs can spread out over soft sediment. The reef structure its self can also engineer the physical environment around it (Roberts *et al.*, 2009). The reef structure created by *Lophelia pertusa* modifies the water flow regime within the reef (Mullins *et al.*, 1981). The complex structure of the reef slows down water flow and this can cause sediments to fall out of suspension. The reef also provides a wide range of niches for other species, and the increase in biological activity within the reef can also increase sedimentation (Roberts *et al.*, 2009).   In addition, the interaction of tidal currents and the mounds and reefs created by cold-water corals can induce the downwelling of surface waters (Robert *et al.*, 2009), which in turn provides a pathway for organic matter to reach 600 metre deep cold-water corals along the Rockall Bank (Soetaert *et al.*, 2016).

Maier (2008) found that, in aquaria, severely fragmented pieces of *Lophelia pertusa* collected during survey work showed considerable recovery potential. Damaged *Lophelia pertusa* were maintained in aquaria for a number of months, during which time they were fed regularly. During the time of experiment corallite pieces as small as 3 mm showed regeneration (Maier, 2008). Maier (2008) noted that although this regeneration was possible within aquaria, corals are not guaranteed to survive damage in the field due to the destruction of the coral framework, sedimentation and other factors not present in the aquaria experiment. However, it does show that cold-water coral propagation within aquaria is possible.

Gass & Roberts (2006) examined 14 oil and gas platforms within the North Sea and found *Lophelia pertusa* to be growing on 13 of them. Two of the platforms were examined more closely and 947 individual colonies were found, the largest of which was 132 cm in diameter (Gass & Roberts, 2006). Prior to the oil and gas platforms in the North Sea, there were no known records of live *Lophelia pertusa*. Larvae recruited to these North Sea platforms were probably transported in the North Atlantic water mass entering the North Sea. The nearest known *Lophelia pertusa* colonies to the North Sea are from the west coast of Scotland. *Lophelia pertusa* larvae are most likely to have reached the North Sea via the substantial inflow of Atlantic water flowing southwards east of Shetland from the Atlantic shelf edge current and the Fair Isle Current (Roberts, 2002; taken from Gass & Roberts, 2006).

Evidence of reef recovery within the field is severely lacking. Roberts *et al.* (2006) stated that cold-water coral reefs have been severely damaged by trawling for deep-water fish, causing severe physical damage from which recovery to former reef status will take several hundred or thousands of years, if at all (Freiwald *et al.*, 2004; Fosså *et al.*, 2002; Hall-Spencer, 2002). Growth rates are slow, the age of the reefs which have been carbon dated show that they have been undisturbed for long periods of time. For a single *Lophelia pertusa* colony to grow to 1.5 m high could take 200 -366 years depending on growth rate (Rogers, 1999). Colonies of *Lophelia pertusa* growing in close proximity merge to create a reef structure. Old reefs can create mounds tens of metres high, and hundreds of metres wide. The period of time for which *Lophelia pertusa* reefs to return to full

ecosystem function is unclear but an estimate of hundreds of years is not unrealistic. If a reef thousands of years old has been damaged then the time for the reef to return to its previous state would take an equal length of time if conditions for recruitment were still favourable. The formation of cold-water coral reefs is complex and fully explained by Roberts *et al.* (2009).

Resilience assessment. The ability of *Lophelia pertusa* to recover from natural or anthropogenic damage is poorly understood (Brooke & Jarnegren, 2013). There is extensive evidence for the damage of *Lophelia pertusa,* yet there is no evidence for the natural recovery of any of these damaged reefs. From experiments within controlled aquaria, there is evidence that *Lophelia pertusa* can recover from very small fragments (Maier, 2008). However, there is no evidence of this occurring in the field. Oil and gas platforms provide evidence that the larvae of *Lophelia pertusa* have the potential to travel extensive distances and can grow to considerable sizes within 20 – 30 years. Although this evidence suggests that *Lophelia pertusa* has the potential to recover relatively quickly within certain controlled aquaria conditions, it does not take into consideration the age of the *Lophelia pertusa* reefs that are the basis of this biotope. The oldest *Lophelia pertusa* reefs in the North East Atlantic were found to be between 7800 – 8800 (Mikkelson *et al.*, 1982; Hovland *et al.*, 1998; Hovland & Mortensen, 1999). It is now widely accepted that anthropogenic pressures are having a negative effect on cold-water coral reefs, including those containing *Lophelia pertusa* (Roberts & Cairns 2014). However, the limited knowledge regarding the worldwide distribution of the cold-water coral reef habitats makes it very difficult to determine how much habitat has been lost to anthropogenic pressures. There are, however, a number of recorded cases of *Lophelia pertusa* reefs being lost from the North East Atlantic. Fosså *et al.* (2002) documented and photographed the damage caused to west Norwegian *Lophelia pertusa* reefs by trawling activity (see Fosså, 2003 for photographs). They reported that four, out of five sites studied, contained damaged corals. In the shallow regions of Sørmannsneset, only fragments of dead *Lophelia pertusa* were seen, spread around the site with no evidence of living colonies in the surrounding area, and Fosså *et al.* (2002) concluded that the colonies had been "wiped out". Overall, they estimated that between 30 and 50% of *Lophelia pertusa* reefs are either impacted or destroyed by bottom trawling in western Norway. From the west coast of Ireland, widespread bottom trawling damage of *Lophelia pertusa* reefs has been found between 840 – 1300 m (Hall-Spencer *et al.*, 2002). *Lophelia pertusa* has also been identified within the by-catch of deep-water fishing vessels trawling off the west coast of Ireland (Hall-Spencer *et al.*, 2002). Other papers that provide evidence for the damage of cold-water coral reefs through bottom trawling include Hall-Spencer *et al.* (2002), Grehan *et al.* (2003), Wheeler *et al.* (2005), Roberts *et al.* (2006), Alhaus *et al.* (2009), Roberts & Cairns (2014). In addition to deep water fisheries, the hydrocarbon industry, mining, and ocean acidification have all been found to degrade the health of cold-water coral reefs (Roberts *et al.*, 2009).

Therefore, where resistance is 'None', 'Low', 'Medium', resilience is assessed 'Very low'. There is no evidence from case studies that show *Lophelia pertusa* reefs recover from damage, so it is unclear if a *Lophelia pertusa* reef will ever recover.

🚢 Hydrological Pressures

	Resistance	Resilience	Sensitivity
Temperature increase (local)	Medium	Very Low	Medium
	Q: High A: High C: Low	Q: High A: High C: High	Q: High A: High C: Low

Lophelia pertusa distribution is controlled by a number of environmental factors, including;

temperature, oxygen saturation, food supply, availability of suitable substratum, and carbonate chemistry (Davies *et al.*, 2008; Roberts *et al.*, 2009; Georgian *et al.*, 2014). The distribution of *Lophelia pertusa* in the North Atlantic appears to correlate with water masses within certain temperature ranges rather than other environmental factors (Frederiksen *et al.*, 1992; Freiwald,1998). *Lophelia pertusa* is typically found in areas where temperatures range from 4 to 12°C (Davies *et al.*, 2008; Robert *et al.*, 2006; Lunden *et al.*, 2014). *Lophelia pertusa* around the UK, Ireland, Norway are found in water temperatures 6 to 8°C (Zibrowius, 1980; Frederiksen *et al.*, 1992; Freiwald *et al.*, 2004), while Tursi *et al.* (2004) recorded *Lophelia pertusa* living within areas with sea temperatures between 12.5 to 14°C in the Mediterranean.

A single *Lophelia pertusa* was reported on the Beryl Alpha platform between depths of 75 and 114 m (Roberts, 2002a). The water column around the platform was stratified; the salinity varied from 34.8 ppt at the surface to just over 35 ppt at 50 m, while the surface temperature remained fairly constant at 11.5°C to a depth of 50 m before dropping rapidly to 8°C between 70 and 110 m (Roberts, 2002a). Roberts (2002a) noted that the depth of *Lophelia pertusa* corresponded with 8°C and a salinity of 35 ppt. He suggested that *Lophelia pertusa* was restricted to depths of greater than 70 m by the temperature and salinity, competition from other epifauna (e.g. sponges and sea anemones) and possibly by wave action during storms (Roberts, 2002a).

Temperature fluctuations measured within *Lophelia pertusa* reefs typically range between 1 and 2°C (Schroeder, 2002; Wisshak *et al.*, 2005; Davies *et al.*, 2009; cited by Form & Riebesell, 2012). Rogers (1999) suggested that the death of coral on the upper reaches of a reef may reflect changes in the depth of the thermocline. But the upper limit of the *Lophelia pertusa* reefs may be attributed to other factors, e.g. the origin of the water masses, salinity, wave action, or competition with other species e.g. sponges (Frederiksen *et al.*, 1992; Rogers, 1999; Mortensen *et al.*, 2001; Dr Alex Rogers, 2005 pers comm.).

Dodds *et al.* (2007) found that the metabolic rates of *Lophelia pertusa* increased dramatically when specimens collected from the Mingulay Reef complex were exposed to temperatures greater than those experienced within the reef. An increase in temperature from 6.5 to 9°C and 9°C to 11°C (ca 2°C) resulted in a doubling in oxygen consumption (Dodds *et al.*, 2007). Dodds *et al.* (2007) suggested that the physiological response observed indicated a sensitivity to even this small a temperature change. Naumann *et al.* (2014) examined the respiration rate and calcification rates of *Lophelia pertusa* collected from the Mediterranean at 12, 9 and 6°C after acclimation for one month. *Lophelia pertusa* was found to acclimate to lower temperatures (9 and 6°C) and maintained a constant respiration rate although calcification rates were reduced by 58% at 6°C. Lunden *et al.* (2014) found that when *Lophelia pertusa*, collected from the Gulf of Mexico, were exposed to temperatures of 14°C in the laboratory experienced 47% mortality within seven days and 100% mortality in the subsequent three week recovery period; at 16°C mortality was 100% after seven days.

Brooke *et al.* (2013) examined the thermal tolerance of *Lophelia pertusa* fragments from the Gulf of Mexico to a range of temperatures (5, 8, 15, 20 and 25°C) for periods of 24 hrs and seven days. Survival was ca 60% after 24 hrs at 20°C but only ca 20% after seven days. Survival was relatively high (ca 80%) after seven days at 15°C, although there was variation in survival between replicates. Survival was also high (a mean of ca 90% but a range of 55-100%) after six months in fragments transplanted (on benthic landers to 418 or 450 m) to the waters of North Carolina, which experienced a wider range of temperatures than the Gulf of Mexico. Brooke *et al.* (2013) noted that deep coral reefs of the southeastern United States experience temperature fluctuations from a mean of ca 8.5°C to a spike of 15°C for hours to days. Guihen *et al.* (2012) also

reported marked temperature fluctuations on the Tisler Reef, Norway in 2006 and 2008 where the temperature rose by ca 4°C in 24 hrs, spiked at 12°C and remained above 10°C for ca 30 days. No mortality of *Lophelia* was observed, although the periods of warm water coincided with the mass mortality of the resident population of the deep-water sponge *Geodia baretti* (Guihen *et al.*, 2012). Brooke *et al.* (2013) concluded that *Lophelia pertusa* had a high tolerance to temperature fluctuations, as it was exposed to rapid and frequent changes to 15°C (possibly higher) and that these exposures were too brief to adversely affect the survival of the coral colonies.

Sensitivity assessment. *Lophelia pertusa* is an extremely long-lived species and is found in deep water where short-term temperature fluctuations found are typically 1-2°C. It was thought to be stenothermal; adapted to relatively stable thermal conditions in deep water (see Rogers, 1999). However, exceptional short-term and rapid temperature changes have been recorded in the Tisler Reef, Norway and may be routine in the Gulf of Mexico or off the coast of North Carolina (Guihen *et al.*, 2012; Brooke *et al.*, 2013). An upper temperature limit of 14°C is suggested for *Lophelia pertusa* by the observations of Lunden *et al.* (2014) while the observations of Brook *et al.* (2003) suggest it may be higher. It is probable that local populations can adapt to local conditions. Nevertheless, the evidence suggests (Guihen *et al.*, 2012; Brooke *et al.*, 2013) that *Lophelia* reefs in the North East Atlantic could probably survive a localised short-term increase in temperature of 5°C for a month, as long as the temperature did not exceed 14-15°C. A prolonged increase of 2°C for a year would probably result in an increase in metabolic rate (Dodds *et al.*, 2007) with a resultant increase in food demand. However, Roberts *et al.* (2009) noted that downwelling of warmer (by 0.75°C) water within the Mingulay Reef (in response to the tidal cycle) would increase the corals' metabolic rate at the same time as supplying increased food. The effects of a prolonged chronic increase in temperature (e.g. 2°C for a year, the benchmark) could probably depend on location of the reef and other factors such as food supply but there is no empirical evidence of the effect of temperature changes at the level of the benchmark. It is also noted that while Brooke *et al.* (2013) recorded a high survivorship (a mean of ca 90%) in transplanted fragments after six months, the range of mortality was 0-45%. Therefore, resistance is assessed as **'Medium'** as a precaution based on possible long-term effects of increased temperature or exposure to localised thermal effluent. Hence, resilience is assessed as **'Very Low'** and sensitivity as '**Medium**'.

Temperature decrease (local)	Medium	Very Low	Medium
	Q: High A: Medium C: Low	Q: High A: High C: High	Q: High A: Medium C: Low

Lophelia pertusa distribution is controlled by a number of environmental factors, including; temperature, oxygen saturation, food supply, availability of suitable substratum, and carbonate chemistry (Davies *et al.*, 2008; Roberts *et al.*, 2009; Georgian *et al.*, 2014). The distribution of *Lophelia pertusa* in the North Atlantic appears to correlate with water masses within certain temperature ranges rather than other environmental factors (Frederiksen *et al.*, 1992; Freiwald,1998). *Lophelia pertusa* is typically found in areas where temperatures range from 4 to 12°C (Davies *et al.*, 2008; Robert *et al.*, 2006; Lunden *et al.*, 2014). *Lophelia pertusa* around the UK, Ireland, Norway are found in water temperatures 6 to 8°C (Zibrowius, 1980; Frederiksen *et al.*, 1992; Freiwald *et al.*, 2004), while Tursi *et al.* (2004) recorded *Lophelia pertusa* living within areas with sea temperatures between 12.5 to 14°C in the Mediterranean.

A single *Lophelia pertusa* was reported on the Beryl Alpha platform between depths of 75 and 114 m (Roberts, 2002a). The water column around the platform was stratified; the salinity varied from 34.8 ppt at the surface to just over 35 ppt at 50 m, while the surface temperature remained fairly constant at 11.5°C to a depth of 50 m before dropping rapidly to 8°C between 70 and 110 m

(Roberts, 2002a). Roberts (2002a) noted that the depth of *Lophelia pertusa* corresponded with 8°C and a salinity of 35 ppt. He suggested that *Lophelia pertusa* was restricted to depths of greater than 70 m by the temperature and salinity, competition from other epifauna (e.g. sponges and sea anemones) and possibly by wave action during storms (Roberts, 2002a).

Temperature fluctuations measured within *Lophelia pertusa* reefs typically range between 1 and 2°C (Schroeder, 2002; Wisshak *et al.*, 2005; Davies *et al.*, 2009; cited by Form & Riebesell, 2012). Rogers (1999) suggested that the death of coral on the upper reaches of a reef may reflect changes in the depth of the thermocline. But the upper limit of the *Lophelia pertusa* reefs may be attributed to other factors, e.g. the origin of the water masses, salinity, wave action, or competition with other species e.g. sponges (Frederiksen *et al.*, 1992; Rogers, 1999; Mortensen *et al.*, 2001; Dr Alex Rogers, 2005 pers comm.).

Dodds *et al.* (2007) found that the metabolic rates of *Lophelia pertusa* increased dramatically when specimens collected from the Mingulay Reef complex were exposed to temperatures greater than those experienced within the reef. An increase in temperature from 6.5 to 9°C and 9°C to 11°C (ca 2°C) resulted in a doubling in oxygen consumption (Dodds *et al.*, 2007). Dodds *et al.* (2007) suggested that the physiological response observed indicated a sensitivity to even this small a temperature change. Naumann *et al.* (2014) examined the respiration rate and calcification rates of *Lophelia pertusa* collected from the Mediterranean at 12, 9 and 6°C after acclimation for one month. *Lophelia pertusa* was found to acclimate to lower temperatures (9 and 6°C) and maintained a constant respiration rate although calcification rates were reduced by 58% at 6°C. Lunden *et al.* (2014) found that when *Lophelia pertusa*, collected from the Gulf of Mexico, were exposed to temperatures of 14°C in the laboratory experienced 47% mortality within seven days and 100% mortality in the subsequent three week recovery period; at 16°C mortality was 100% after seven days.

Brooke *et al.* (2013) examined the thermal tolerance of *Lophelia pertusa* fragments from the Gulf of Mexico to a range of temperatures (5, 8, 15, 20 and 25°C) for periods of 24 hrs and seven days. Survival was ca 60% after 24 hrs at 20°C but only ca 20% after seven days. Survival was relatively high (ca 80%) after seven days at 15°C, although there was variation in survival between replicates. Survival was also high (a mean of ca 90% but a range of 55-100%) after six months in fragments transplanted (on benthic landers to 418 or 450 m) to the waters of North Carolina, which experienced a wider range of temperatures than the Gulf of Mexico. Brooke *et al.* (2013) noted that deep coral reefs of the southeastern United States experience temperature fluctuations from a mean of ca 8.5°C to a spike of 15°C for hours to days. Guihen *et al.* (2012) also reported marked temperature fluctuations on the Tisler Reef, Norway in 2006 and 2008 where the temperature rose by ca 4°C in 24 hrs, spiked at 12°C and remained above 10°C for ca 30 days. No mortality of *Lophelia* was observed, although the periods of warm water coincided with the mass mortality of the resident population of the deep-water sponge *Geodia baretti* (Guihen *et al.*, 2012). Brooke *et al.* (2013) concluded that *Lophelia pertusa* had a high tolerance to temperature fluctuations, as it was exposed to rapid and frequent changes to 15°C (possibly higher) and that these exposures were too brief to adversely affect the survival of the coral colonies.

Sensitivity assessment. *Lophelia pertusa* is an extremely long-lived species and is found in deep water where short-term temperature fluctuations found are typically 1-2°C. It was thought to be stenothermal; adapted to relatively stable thermal conditions in deep water (see Rogers, 1999). However, exceptional short-term and rapid temperature changes have been recorded in the Tisler Reef, Norway and may be routine in the Gulf of Mexico or off the coast of North Carolina (Guihen *et al.*, 2012; Brooke *et al.*, 2013). An upper temperature limit of 14°C is suggested for *Lophelia*

pertusa by the observations of Lunden *et al.* (2014) while the observations of Brook *et al.* (2003) suggest it may be higher. It is probable that local populations can adapt to local conditions. Nevertheless, the evidence suggests (Guihen *et al.*, 2012; Brooke *et al.*, 2013) that *Lophelia* reefs in the North East Atlantic could probably survive a localised short-term increase in temperature of 5°C for a month, as long as the temperature did not exceed 14-15°C. A prolonged increase of 2°C for a year would probably result in an increase in metabolic rate (Dodds *et al.*, 2007) with a resultant increase in food demand. However, Roberts *et al.* (2009) noted that downwelling of warmer (by 0.75°C) water within the Mingulay Reef (in response to the tidal cycle) would increase the corals' metabolic rate at the same time as supplying increased food. The effects of a prolonged chronic increase in temperature (e.g. 2°C for a year, the benchmark) could probably depend on location of the reef and other factors such as food supply but there is no empirical evidence of the effect of temperature changes at the level of the benchmark, especially a decrease in temperature. It is also noted that while Brooke *et al.* (2013) recorded a high survivorship (a mean of ca 90%) in transplanted fragments after six months, the range of mortality was 0-45%. Therefore, resistance is assessed as **'Medium'** as a precaution based on possible long-term effects of increased temperature or exposure to localised thermal effluent. Hence, resilience is assessed as **'Very Low'** and sensitivity as '**Medium**'.

Salinity increase (local)	Low	Very Low	High
	Q: Medium A: Medium C: Medium	Q: High A: High C: High	Q: Medium A: Medium C: Medium

Lophelia pertusa occurs in waters of 35 -37 psu but in fjords tolerates salinities as low as 32 psu (Rogers, 1999; Mortensen *et al.*, 2001). However, Rogers (1999) regarded *Lophelia pertusa* to be stenohaline. The *Lophelia pertusa* reef and its associated fauna occur in relatively stable waters, which are not subject to fluctuations in salinity. While *Lophelia pertusa* is probably highly intolerant of changes in salinity at the benchmark level, it is unlikely to experience an increase in salinity except in rare cases such as the unlikely production of hypersaline effluents by offshore installations.

Sensitivity assessment. Due to the highly stable conditions in which *Lophelia pertusa* is usually found a change in salinity is likely to cause mortality of the coral polyps. Consequently, resistance has been assessed as **'Low'**, resilience as **'Very low'**, and sensitivity assessed as **'High'**.

Salinity decrease (local)	Low	Very Low	High
	Q: High A: Medium C: Medium	Q: High A: High C: High	Q: Medium A: Medium C: Medium

Lophelia pertusa occurs in waters of 35 - 37 psu but in fjords tolerates salinities as low as 32 psu (Rogers, 1999; Mortensen *et al.*, 2001). However, Rogers (1999) regarded *Lophelia pertusa* to be stenohaline. The *Lophelia pertusa* reef and its associated fauna occur in relatively stable waters, which are not subject to fluctuations in salinity. While *Lophelia pertusa* is probably highly intolerant of changes in salinity at the benchmark level, it is unlikely to experience a decrease in salinity except in rare cases. However, in shallow fjordic water *Lophelia pertusa* is restricted to the deeper, stable oceanic water below the relatively reduced salinity coastal waters at the surface. An increase in freshwater runoff may increase the depth of the pycnocline and would probably result in the death of the upper extent of the reef.

Sensitivity assessment. Resistance has been assessed as **'Low'** and resistance as **'Very Low'** so that overall sensitivity is assessed as of **'High'** at the level of the benchmark.

Water flow (tidal current) changes (local)	High	High	Not sensitive
	Q: High A: High C: Medium	Q: High A: High C: High	Q: High A: High C: Medium

Early records of cold-water coral reefs are associated with strong water flows (Roberts *et al.*, 2009). Further investigation found that *Lophelia pertusa* reefs occur where the topography causes current acceleration, e.g. on raised seabed features (e.g. seamounts and banks) and where the channel narrows in Norwegian fjords (Rogers, 1999). Higher water flow rates are thought to aid the two dominant food supply mechanisms to *Lophelia pertusa* (Roberts *et al.*, 2009). The two mechanisms are; the regular rapid downwelling of surface water delivering pulses of warm nutrient-rich surface water, and, the periodic advection of high turbidity bottom waters (Roberts *et al.*, 2009). Frederiksen *et al.* (1992) suggested that topographical highs create internal waves that re-suspended organic particulates from the seabed, and increase the flux of nutrient-rich waters to the surface waters increasing phytoplankton productivity; both effects resulting in increased food availability for *Lophelia pertusa* and other suspension feeders.

Frederiksen *et al.* (1992) suggested that *Lophelia pertusa* reefs around the Lousy and Hatton Banks would typically encounter currents speeds of 0.01-0.1 m/s. Water flow rates >0.4 m/s were recorded by moored and landed deployed current meters close to deep-water coral mounds in the Porcupine Seabight (Grehan *et al.*, 2003), while Masson *et al.* (2003) recorded a maximum residual bottom water flow of 0.35 m/s over a 20 day period in July 2000 over the Darwin Mounds. Currents speeds of 0.01 -0.1 m/s, 0.35 or 0.4 m/s approximate to between weak and moderately strong water flow. However, oceanic and tidal currents in the region of the Faroes were reported to be about 0.5 m/s (moderately strong) and in the region of west Shetland 0.5 to 0.7 m/s or more (moderately strong). Meinis *et al.* (2007) reported current speeds of up to 0.45 m/s, with a residual current of 0.1 m/s, along coral mounds on the southwest Rockall Trough. Similarly, Davies *et al.* (2008) reviewed the environmental parameters for the occurrence of *Lophelia pertusa*. They concluded that it occupied a niche where the current speed (ranging from 0.004 to 0.51 m/s, with a mean of 0.07 m/s) and productivity (a mean of 0.9 mg/m3) were higher than average. They reported that globally *Lophelia* was associated with high productivity and irregular topography.

Mortensen (2001) investigated the growth and behaviour of *Lophelia pertusa* in an aquarium with flowing seawater. No polyp mortality was observed in the vicinity of his aquaria inlets but high mortality at the opposite end. Similarly, the death of coral polyps within a coral coppice was thought to be due to reduced water flow within the colony (Wilson, 1979b). Mortensen (2001) also noted that high current flow (greater than ca 0.05 m/s) was detrimental to growth, presumably due to reduced food capture rates. Purser *et al.* (2010) collected samples of *Lophelia pertusa* from the Tisler reef off Norway. They then kept them in controlled laboratory aquaria and tested the effect of flow velocity on food capture rates. Flow rates were kept at 0.025 m/s and 0.05 m/s, and the reduction in *Artemia salina* nauplii concentrations was recorded. Maximum net capture rates were found at the 0.025 m/s (Purser *et al.*, 2010). Orejas *et al.* (2016) also concluded from flume studies that water flow rates impacted food capture efficiency in *Lophelia pertusa*. It mostly captured zooplankton at low flow speeds of 0.02 m/s and phytoplankton at 0.05 m/s and that polyp expansion was greatest at low flow speeds of 0.005 and 0.67 m/s rather than at 0.15 and 0.27 m/s. Although, cold-water coral reefs are associated with areas of high bottom currents velocities (as above), Orejas *et al.* (2016) noted that strong currents were often short-lived and driven by tidal events and that currents were slow for several hours between tidal cycles, for example in the Mingulay Reef velocity could decrease to less than 0.02 m/s during each tidal cycle. In addition, the structure of the coral matrix also slows the currents locally within the coral matrix itself and the reef colonies probably dissipate higher current velocities with increasing size (Orejas *et al.*, 2016).

Sensitivity assessment. *Lophelia pertusa* reefs probably rely on constant, mass water flow to supply food and nutrients and prevent the build-up of sediment, interspersed with slack periods or lower flow to allow optimal feeding, although the coral matrix itself probably slows water flow within the reef. A decrease in water flow across the reef would reduce the availability of food, which may decrease the health of the *Lophelia pertusa* colony. If it were reduced below a certain level, mortality could occur. Although *Lophelia pertusa* relies on water flow, Mortensen's data (2001) suggests a sustained water flow over 0.05 m/s may reduce growth. Areas in which *Lophelia pertusa* reefs are found experience great changes in water flow rates throughout the tidal cycle. As long as the increase in water flow rate did not mean that water flow rates were permanently above 0.05 m/s, the pressure at the benchmark is unlikely to have a negative impact on the biotope. Therefore, both resistance and resilience have been assessed as '**High**', and sensitivity assessed as '**Not sensitive**' at the benchmark level.

Emergence regime changes	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Lophelia pertusa do not occur in the intertidal, they occur in oceanic waters, at depths of over 200 m, except in Norwegian fjords where it upper depth limit may be 50 m, below the influence of coastal waters. Therefore, it is unlikely to be affected by changes in the emergence regime and **'Not relevant'** has been recorded.

Wave exposure changes (local)	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Offshore *Lophelia pertusa* reefs occur, by definition, in extremely wave exposed conditions, although wave action is ameliorated by depth. Draper (1967) noted that wave periods in offshore areas are generally of longer than in enclosed seas and therefore penetrates to greater depths. However, Draper (1967) estimated that as far out as the continental shelf, for one day a year, storm conditions could generate an oscillatory water movement on the seabed of only ca 0.4 m/s at 180 m. In Norwegian fjords where *Lophelia pertusa* reefs occur as shallow as 50 m, wave action is slight at the surface and most likely does not penetrate more than a few tens of metres. Inner fjords have limited fetch so that wave action is unlikely to penetrate to more than a few tens of metres even in storm conditions (Dr Keith Hiscock pers. comm.).

The oscillatory water movement generated by wave action could potentially result in fragmentation of branching coral skeletons at the upper limit of their depth distribution, although their skeletons are fairly robust. Occasional fragmentation may not unduly affect the reef but allow it to spread in the long-term as the fragments continue to grow, or provide a substratum for colonization by *Lophelia pertusa* larvae. However, *Lophelia pertusa* occurs at depths at which even the wave action generated by storm conditions is unlikely to penetrate. Therefore, '**Not relevant**' has been recorded.

⚗ Chemical Pressures

	Resistance	Resilience	Sensitivity
Transition elements & organo-metal contamination	Not Assessed (NA)	Not assessed (NA)	Not assessed (NA)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Hydrocarbon & PAH contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Synthetic compound contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Radionuclide contamination	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No evidence.

Introduction of other substances	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed.**

De-oxygenation	Low Q: High A: High C: Medium	Very Low Q: High A: High C: High	High Q: High A: Medium C: Medium

It has been suggested that the lower limit of *Lophelia pertusa's* bathymetric distribution is partially determined by the oxygen minimum zone (Freiwald, 1998; Rogers, 1999). Roberts *et al.* (2003) suggested the lower depth limit of *Lophelia pertusa*'s distribution in the North East Atlantic was related to temperature. It is likely to be a combination of factors which determine the distribution of *Lophelia pertusa* (Davies *et al.*, 2008; Roberts *et al.*, 2009).

Dodds *et al.* (2007) investigated the metabolic tolerance of *Lophelia pertusa* to temperature and dissolved oxygen change in the laboratory. They found that *Lophelia pertusa* could survive anoxia for 1 hour, and hypoxia (2-3 kPa; 0.88-1.32 mg/l) for 96 hours (4 days). *Lophelia pertusa* was able to increase its uptake of oxygen by the expansion of the surface area of its polyp in response to low oxygen concentrations (Dodds *et al.*, 2007). *Lophelia pertusa* was able to regulate its oxygen consumption until the oxygen concentration fell below 98-10 kPA at 9°C. Dodds et al. (2007) suggested that the critical oxygen concentration for this species, below which it would not be able to carry out normal aerobic function was ca 9.5 kPa (ca 3.26 ml/l; ca 4.56 mg/l). Davies *et al.* (2008) mapped the suitable habitat for *Lophelia pertusa* and found that *Lophelia pertusa* records were associated with areas of water with an ambient oxygen concentration between 4.3 – 7.2 ml/l (6.47-10.35 mg/l), with a mean of 6-6.2 ml/l, and that the species was not found in areas where the oxygen concentration was less than 2.37 ml/l (3.32 mg/l). Lunden *et al.* (2014) studied, among other things, the effect of decreasing oxygen concentration of *Lophelia pertusa* collected from the Gulf of Mexico. Oxygen concentrations within the Gulf of Mexico are lower than those recorded in the North East Atlantic, with records ranging from 1.5 – 3.2 ml/l (Lunden *et al.*, 2014). Laboratory experiments exposed *Lophelia pertusa* to different oxygen concentrations for 7 days. The *Lophelia*

pertusa samples survived (100%) exposure to 5.3 and 2.9 ml/l but 100% mortality at ca 1.57 ml/l (ca 2.2 mg/l) after 7 days.

Sensitivity assessment.   A change in oxygen concentration at the benchmark (2 mg/l or less for a week) has the potential to cause significant mortality in cold-water reefs in North East Atlantic. The evidence suggests that if the mean oxygen concentration fell below 3.26 ml/l, (ca 4.56 mg/l) then mortality could occur within the area and if the oxygen concentration fell below 2.2 mg/l for a week (see Lunden *et al.*, 2014), 100% mortality is possible. Therefore, resistance is assessed as **'Low'**, and resilience is assessed as **'Very low,** so that sensitivity assessment is probably **'High'**.

Nutrient enrichment	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

The physical structure and position of cold-water coral structures (reefs and mounds) have been shown to induce up-welling and down-welling events, determined by the tidal currents and the tidal cycles, that provide food to the reef and link surface water productivity with deep waters (Roberts *et al.*, 2009; Soetaert *et al.*, 2016; Kazanditis & Witte, 2016). The nutrient levels (e.g. nitrates, phosphates, and ammonia) and inorganic carbon in the vicinity of cold-water coral reefs in the North East Atlantic vary with the tidal cycle and with depth (Findlay *et al.*, 2014). For example, Findlay *et al.* (2014) reported a range of inorganic carbon of 2088 to 2186 µmol/kg and nitrate (NO_3) or 4.1-18.8 µmol/l in the sites they examined in the North East Atlantic. Davies *et al.* (2008) also report a range of nitrate levels of 8 - 23.4 µM (mean of 13.8 µM) for sites where *Lophliea pertusa* was recorded in the North East Atlantic. Davies *et al.* (2008) noted a negative correlation between high nutrient concentrations (nitrate, phosphate and silicate) with *Lophelia pertusa* distribution. They also noted that the species was also not found in the lowest nutrient concentrations and that while high nutrient levels limited distribution, the species probably required intermediate levels (Davies *et al.*, 2008).

The evidence suggests that high or low nutrient levels, when compared across the North East Atlantic (Davies *et al.*, 2008) may be detrimental. Nevertheless, no information on the effect of nutrient enrichment on cold-water coral reefs or mounds was found. Therefore, 'No evidence' is recorded.

Organic enrichment	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

The physical structure and position of cold-water coral structures (reefs and mounds) have been shown to induce up-welling and down-welling events, determined by the tidal currents and the tidal cycles, that provide food to the reef and link surface water productivity with deep waters (Roberts *et al.*, 2009; Duineveld *et al.*, 2012; Soetaert *et al.*, 2016; Kazanidis & Witte, 2016). Kazanidis & Witte (2016) note that the supply of organic matter to the cold-water corals also benefits other suspension feeders in the community. For example, the Mingulay area had a higher biomass of suspension or filter feeders than the Logachev area. Kazanidis & Witte (2016) suggested that this was due to the benthopelagic coupling of highly productive surface waters with the reef and higher velocity of bottom currents in the Migulary area compared to the Logachev area.

Nevertheless, no information on the effect of organic enrichment (at the level of the benchmark) on cold-water coral reefs or mounds was found. Therefore, 'No evidence' is recorded.

🔭 Physical Pressures

	Resistance	Resilience	Sensitivity
Physical loss (to land or freshwater habitat)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

All marine habitats and benthic species are considered to have a resistance of 'None' to this pressure and to be unable to recover from a permanent loss of habitat (resilience is 'Very Low'). Sensitivity within the direct spatial footprint of this pressure is, therefore 'High'. Although no specific evidence is described confidence in this assessment is 'High', due to the incontrovertible nature of this pressure.

Physical change (to another seabed type)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

Lophelia pertusa larvae must settle onto hard substrata (Roberts *et al.*, 2009) to enable them to find a solid anchor point, from which the hard skeleton of the coral can attach. The presence of *Lophelia pertusa* on oil and gas platforms (Gass & Roberts, 2006), suggests that their larvae are able to settle onto artificial substrata. There is no information available on the preference of *Lophelia pertusa* larvae for certain types of hard substrata. However, for a change in substrata to occur, the original substratum would need to be removed first, which would result in removal of living coral and dead coral debris, resulting in the destruction of the reef and loss of the biotope.

Sensitivity assessment. Therefore, a resistance of 'None' and a resilience of 'Very Low' have been recorded, resulting in a sensitivity of 'High'.

Physical change (to another sediment type)	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Lophelia pertusa larvae have to settle onto a hard substratum. The branching nature of this reef forming species means that their structures can extend out over soft substratum. However, as this species requires a hard substratum onto which to anchor, a change in soft sediment type is Not relevant to this biotope. Hence, the pressure is assessed as 'Not relevant'.

Habitat structure changes - removal of substratum (extraction)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

Lophelia pertusa larvae have to settle onto hard substrata. However, a large reef may grow out over soft sediment, from which sediment may be extracted. The reef structure can also significantly change the water flow rates, which can mean that sediment being carried in suspension, is deposited in the reef. Extraction of substratum to 30 cm within this biotope would mean that all of the reef forming, characterizing species, *Lophelia pertusa,* would be removed. This would entirely destroy the habitat and would result in the loss of the biotope.

Sensitivity assessment. *Lophelia pertusa* and the biotope have no resistance the removal of substratum to 30 cm, therefore, the resistance is assessed as 'None'. The extremely long lived nature and slow growth rate of the characterizing species *Lophelia pertusa* means that resilience is

'Very Low', giving this biotope an overall sensitivity assessment of 'High'.

Abrasion/disturbance of the surface of the substratum or seabed

None	Very Low	High
Q: High A: High C: High	Q: High A: High C: High	Q: High A: High C: High

Although *Lophelia pertusa* reefs occur at great depths, they are likely to be subject to physical disturbance due to anchorage or positioning of offshore structures on the seabed but especially due to deep-sea trawling. Rogers (1999) suggested that trawling gear would break up the structure of the reef, fragment the reefs, and potentially result in the complete disintegration of the coral matrix, and loss of the associated species.

Fosså *et al*. (2002) documented and photographed the damage caused to west Norwegian *Lophelia pertusa* reefs by trawling activity (see Fosså, 2003 for photographs). They reported that four, out of five sites studied, contained damaged corals. In the shallow regions of Sørmannsneset, only fragments of dead *Lophelia pertusa* were seen, spread around the site with no evidence of living colonies in the surrounding area, and Fosså *et al*. (2002) concluded that the colonies had been "wiped out". Overall, they estimated that between 30 and 50% of *Lophelia pertusa* reefs were either impacted or destroyed by bottom trawling in western Norway. Mechanical damage by fishing gear would also damage or kill the associated epifaunal species, some of which are slow-growing e.g. sponges, potentially turn over the coral rubble field, and modify the substratum (Rogers, 1999; Fosså *et al*., 2002). Fosså *et al*. (2002) demonstrated that gorgonian (horny) corals were also torn apart by bottom trawling. Fosså (2003) also note that fixed fishing nets, e.g. gill nets, and long-line fisheries and their associated anchors could potentially result in damage to the reefs such as breakage of the coral colonies. However, damage by long-line or gill net fisheries is probably of limited extent compared to bottom trawling (Fosså, 2003). Hall-Spencer *et al*. (2002) also provided photographic evidence of an area of reef impacted by bottom trawling, with a clearly visible trench (5 -10 cm deep) made by otter boards surrounded by smashed coral fragments in west Norway. Hall-Spencer *et al*. (2002) also noted that otter trawling with rockhopper gear damaged coral habitats in west Ireland, based on analysis of by-catch but also noted that fishing vessels actively avoided rough ground and that the majority of trawls did not result in *Lophelia pertusa* by-catch. Koslow *et al*. (2001) reported that on shallow, heavily fished seamounts off Tasmania, trawling had effectively removed the dominant cold-water coral and its associated fauna. The substratum of heavily fished seamounts was primarily bare rock or coral rubble and sand, features not seen on any lightly fished or un-fished seamount. The abundance and richness of benthic fauna were also "markedly reduced" on heavily fished seamounts (Koslow *et al*. (2001).

Sensitivity assessment. Overall, there is significant evidence of damage to *Lophelia pertusa* and other cold-water coral reefs due to deep-sea trawling. Resistance is assessed as 'None', and resilience is 'Very Low', giving the biotope a sensitivity of 'High'.

Penetration or disturbance of the substratum subsurface

None	Very Low	High
Q: High A: High C: High	Q: High A: High C: High	Q: High A: High C: High

Penetration and or disturbance of the substratum would result in similar, if not identical results as Abrasion or removal of a *Lophelia pertusa* reef and its associated community (see abrasion/disturbance).

Sensitivity assessment. A resistance of 'None' has been given. If the substratum is either penetrated or disturbed, then the overlying reef would also be affected. The extremely long lived and slow growing nature of *Lophelia pertusa*, the characterizing species within this biotopes, means that damage incurred would take an extremely long time to recover. Therefore, resilience has been assessed as 'Very Low' resulting in sensitivity being 'High'.

Changes in suspended solids (water clarity)	Low	Very Low	High
	Q: High A: High C: Medium	Q: High A: High C: High	Q: High A: Medium C: Medium

A change in suspended solids can have two major effects on a biotope. The firstly being that a change in suspended solids can change the levels of light attenuation, and therefore the amount of light which will reach the biotope. However, this biotope is found outside of the photic zone within the North East Atlantic and therefore this is not a consideration. The second effect of a change in suspended solids is the supply of food to the biotope. The characterizing species, *Lophelia pertusa*, is a filter feeding organism and relies on the supply of suspended organic matter for sustenance. The location of *Lophelia pertusa* reefs is determined by a multitude of factors, however, a combination of water flow and seafloor relief are important in regards to the supply of food particles and larvae (Flach & Thomsen 1998; Gage *et al.* 2000; Hughes & Gage, 2004). Reefs are found in areas where the topography works to accelerate near-bed currents, which enhance food supply (Mortensen *et al.*, 2001; Thiem *et al.*, 2006; Kiriakoulakis *et al.*, 2007; Robert *et al.*, 2009; Davies *et al.*, 2009; Soetaert *et al.*, 2016; Kazanditis & Witte, 2016).

Davies *et al.*, (2009) measured the turbidity of the water along a transect within the Mingulay reef complex off the west coast of Scotland. Turbidity levels varied along the transect. However, on the sections of the transect that were closer to the top of the reef, lower turbidity levels appeared to be during the onset of an ebb tide (Davies *et al.*, 2009). Increased turbidity was found to correlate with an increase in the speed of water flow, therefore, throughout the space of one tide, there was considerable variation in the levels of suspended solids within the water column. This information suggests that over a short time period *Lophelia pertusa* and their associated species can tolerate changes in suspended solids.

Brooke *et al.* (2009) compared the tolerance of two morphotypes of *Lophelia pertusa* (gracilis, fragile; brachcephala, heavily calcified) to different levels of turbidity. The fragments collected from the Gulf of Mexico were kept in aquaria, at five different turbidity levels, for 14 days. Both morphotypes of *Lophelia pertusa* found in clear conditions (<10 mg/l) had 100% survival rates. Over 80% of *Lophelia pertusa* kept at intermediate turbidity conditions (10–100 mg/l) survived. Two of the experimental turbidity's fell within the medium turbidity water frame directive (WFD) ranking system, these were 103 mg/l and 245 mg/l. In the former, both morphotypes had a survival rate of >50%, and the later had a survival rate of >30%. Within the very turbid category (ca 362 mg/l) the more fragile morphotype, gracilis, experienced 100% mortality, and brachycephala had an extremely low survival rate (Brooke *et al.*, 2009). From the results of this laboratory experiment, Brooke *et al.* (2009) summarized that *Lophelia pertusa* survival decreased in steps, rather than a continuous linear decline; suggesting that the corals have physiological thresholds beyond which they unable to cope with turbidity levels, at which point mortality can occur.

Mortensen (2001) found that when both food and sediment were presented to *Lophelia pertusa* at the same time sediment was ingested, however, the process of feeding and polyp cleaning do not occur at the same time (Brooke *et al.*, 2009). An increase in turbidity with the *Lophelia pertusa*

environment would lead to more settlement of sediment onto the coral polyps. This would lead to an increase in the amount of time required to remove the sediment from the polyp, which could restrict the amount of time available for feeding. Brooke *et al.* (2009) suggested that this could lead to the starvation of the coral polyp even though food may be available.

However, Larsson *et al.* (2013b) reported that suspended sediment exposure has no significant effect on respiration or fatty acid composition in *Lophelia pertusa* and that the amount of additional mucus produced to clean its polyps was low and di not significantly affect energy expenditure. Larsson *et al.* (2013) exposed *Lophelia pertusa* fragments to fine (<63 μm) natural sediment and drill cuttings at 5 mg/l and 25 mg/l for 12 weeks in the laboratory. After 12 weeks, mortality was low with only 0.3% (1 polyp) dying after exposure to 25 mg/l natural sediment and 2.2% (8 polyps) dying after exposure to 12 weeks but zero in controls. They attributed the mortality to the build-up of sediment on the fragments and potential resultant smothering (see below) (Larsson & Purser, 2011; Larsson *et al.*, 2013b). At the low concentration of sediments, the polyps were fully extended but only half extended at the high concentration and there was a trend towards lower growth rates when exposed to drill cuttings rather than natural sediment Larsson *et al.* (2013b). In addition, in a pilot experiment, Larsson *et al.* (2013a) reported significant mortality (67%) planulae exposed to 25 mg/l of drilling cuttings after 4 days, while mortality at 5 mg/l was low and not significantly different from controls. Larsson *et al.* (2013) also reported that Gilmour (1999; cited in Larsson *et al.*, 2013a) that larval mortality was an average of 98% after 2 days exposure to 50 and 100 mg/l of natural sediment. Nevertheless, Larsson *et al.* (2013a) concluded that *Lophelia pertusa* polyps coped reasonably well with increased suspended sediment and deposition rates. In comparison, information on natural rates of sedimentation experienced in reef habitats is limited. Brooke *et al.* (2009) reported suspended sediment levels of 9-10 mg/l and sedimentation rates of 31 and 47 g/m^2/d at two sites in the Gulf of Mexico. But Larson *et al.* (2013a) noted that these rates were probably high compared to typical 0.5 -3.7 g/m^2/d reported in the North East Atlantic cold-water coral habitats, which in turn suggested that *Lophelia pertusa* was capable of tolerating naturally occurring suspended sediment levels.

A decrease in the levels of suspended material at the level of the benchmark could lead to a reduction in the availability of food to *Lophelia pertusa*, and other filter feeding organisms within the biotope. However, Larsson *et al.* (2013b) reported that *Lophelia pertusa* was highly tolerant of living on minimal resources (food) for several months. In their experiments, *Lophelia* survived (100%) starvation for 28 weeks (Larsson *et al.*, 2013b).

Sensitivity assessment. The evidence suggests that a change in turbidity from clear to intermediate (10m/l to 10-100 mg/l) for a year could result in limited or some mortality but that a change for intermediate to medium turbidity (100-300 mg/) for a year could result in significant mortality depending on duration and local hydrography. For example, Brooke *et al.*, (2009) demonstrated significant mortality after only 14 days at 103 and 245 mg/l. Therefore, resistance is assessed as **'Low'**, resilience as **'Very low'**, and sensitivity is assessed as **'High'** at the benchmark level.

Smothering and siltation rate changes (light)	Medium	Very Low	Medium
	Q: High A: High C: Medium	Q: High A: High C: High	Q: High A: Medium C: Medium

Rogers (1999) suggested that *Lophelia pertusa* would be intolerant of increased rates of sedimentation, caused by decreased water flow, or the resuspension and subsequent sedimentation of sediment by marine activities, such as offshore construction or mobile fishing

gear (e.g. beam or otter trawls), or the discharge of drill cuttings An increase in sedimentation is thought to be one of largest sources of degradation of coral reefs (Norse, 1993) and may suppress the growth rates of *Lophelia* colonies (Fosså *et al.*, 2002). Information on natural rates of sedimentation experienced in reef habitats is limited. Rogers (1999) suggested that sedimentation rates of >10 mg/cm²/day in shallow water coral reefs were high. Brooke *et al.* (2009) reported suspended sediment levels of 9-10 mg/l and sedimentation rates of 31 and 47 g/m^2/d at two sites in the Gulf of Mexico. But Larson *et al.* (2013a) noted that these rates were probably high compared to typical 0.5 -3.7 g/m^2/d reported in the North East Atlantic cold-water coral habitats, which in turn suggested that *Lophelia pertusa* was capable of tolerating naturally occurring suspended sediment levels and sedimentation rates.

Mortensen (2001) reported that 25-100% of polyps died after being starved for 3 months or more but in some cases, polyps survived starvation for 16 and 20 months. However, Larsson *et al.* (2013b) reported that *Lophelia pertusa* was highly tolerant of living on minimal resources (food) for several months. In their experiments, *Lophelia* survived (100%) starvation for 28 weeks (ca six months) (Larsson *et al.*, 2013b).

Preliminary results suggested that sand deposition rates of 0.1 mg/cm²/min significantly reduced polyp expansion in *Lophelia pertusa* (Roberts & Anderson, 2002b), which would reduce feeding and hence growth rates. Mortensen (2001) demonstrated that *Lophelia pertusa* was able to remove sediment particles <3 mm within 3-5 min and 3-5 mm particles within ca 15 min due to the beating of cilia towards the tips of the tentacles, and reported that the living coenosarc (coral tissue) was always clean of sediment. Earlier studies by Shelton (1980), showed that *Lophelia pertusa* could remove graphite particles within ca 30 sec. Similarly, Reigl (1995) demonstrated that scleractinian corals were able to clean sand from their surface actively. When exposed to 200 mg of sand per cm² in a single application, scleractinian corals cleared 50% of the sand within 1000 min, and all the species studied survived for 6 weeks continuous exposure to 200 mg of sand per cm². Reigl (1995) concluded that corals could cope with considerable amounts of sand deposition. Nevertheless, Rogers (1999) suggested that an increase in sedimentation was likely to interfere with feeding and hence growth, which would alter the balance between growth and bioerosion, potentially resulting in degradation of the reef. In addition, smothering could prevent settlement of larvae and hence recruitment.

In burial experiments, Larsson & Purser (2011) exposed *Lophelia* fragments to regular depositions of sediment (<63 µm) over 3 weeks resulting in a covering of the polyps by 6.5 mm or 19.0 mm of sediment. Mortality was low for the duration of the experiment with only 3.7% (seven polyps) dying under 19 mm and 0.5% (one polyp) dying under 6.5 mm of sediment (Larsson & Purser, 2011). Allers *et al.* (2013) investigated the resilience of *Lophelia pertusa* taken off Norway to sedimentation in laboratory-based experiments. They found that both the mucus production and branching morphology of *Lophelia pertusa* meant that accumulation of sediment was relatively slow. Even high sediment deposition (462 mg/cm^2) did not result in complete coverage of the fragments skeleton by sediment. Short-term (<24 hours) exposure to sedimentation reduced the availability of oxygen to *Lophelia pertusa*. However, the organism could tolerate both low-oxygen and anoxic conditions without suffering visible, short-term effects (Allers *et al.*, 2013). As little as 3 mm of sediment covering a *Lophelia pertusa* polyp led to complete anoxia within six days, and the thicker the covering of sediment the faster anoxia occurred (Allers *et al.*, 2013). But complete burial for >24 hours caused suffocation and 100% mortality (Allers *et al.*, 2013). Brooke *et al.* (2009) reported different tolerance of *Lophelia pertusa* to total burial. Samples of *Lophelia pertusa* were collected from the Gulf of Mexico and tested for their tolerance to complete burial in sediment to a depth of over 1 cm. It was found that a significant tolerance threshold was reached

between 2 – 4 days, after which time very low survival rates were recorded and 100% mortality occurred after 7 days (Brooke *et al.*, 2009). In burial experiments, Larsson & Purser (2011) exposed *Lophelia* fragments to regular depositions of sediment (<63 µm) over 3 weeks resulting in a covering of the polyps by 6.5 mm or 19.0 mm of sediment. Mortality was low for the duration of the experiment with only 3.7% (seven polyps) dying under 19 mm and 0.5% (one polyp) dying under 6.5 mm of sediment (Larsson & Purser, 2011).

Sensitivity assessment. At the benchmark level, the majority of the *Lophelia pertusa* polyps would probably be unaffected due to the size of the colony, which is raised above the seabed. The levels of water flow within this environment are recorded as significant, therefore, it is likely that the sediment would be re-suspended, and removed relatively quickly. However, if the sediment were to remain for more than two days then it is likely that any polyps which were buried would suffer mortality. The resistance of this biotope to the pressure at the benchmark is assessed as **'Medium'**, resilience as **'Very low'**, and sensitivity is assessed as **'Medium'**.

Smothering and siltation rate changes (heavy)	Low	Very Low	High
	Q: High A: Medium C: Medium	Q: High A: High C: High	Q: High A: Medium C: Medium

Using the information within provided for the 'light' smothering and siltation pressure, it can be assumed that the burial of *Lophelia pertusa* in 30 cm of sediment would cause considerable damage to the health of this reef forming species. If the sediment were to remain in place for more than two days, any buried polyps are likely to have suffered mortality.

Sensitivity assessment. At the pressure benchmark, resitstance is assessed as **'Low'**, resilience as **'Very low',** and sensitivity as **'High'**.

Litter	Not Assessed (NA)	Not assessed (NA)	Not assessed (NA)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not assessed.

Electromagnetic changes	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No evidence.

Underwater noise changes	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Species characterizing this habitat do not have hearing perception but vibrations may cause an impact, however, no studies exist to support an assessment.

Introduction of light or shading	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Natural light rarely penetrates to the depth this biotope is found in the North East Atlantic. Therefore, an increase in the amount of natural light is 'Not relevant' to this biotope. However,

due to the oil and gas platforms and other forms of exploration or removal of resources, it is possible that un-natural light could be introduced to this biotope. There is no evidence to support an assessment at this pressure benchmark though, and consequently, an assessment of 'No evidence' has been given.

Barrier to species movement	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not relevant – this pressure is considered applicable to mobile species, e.g. fish and marine mammals rather than seabed habitats. Physical and hydrographic barriers may limit propagule dispersal but larval dispersal is not considered under the pressure definition and benchmark.

Death or injury by collision	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not relevant – this pressure is considered applicable to mobile species, e.g. fish and marine mammals rather than seabed habitats.

Visual disturbance	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Not relevant.

🐚 Biological Pressures

	Resistance	Resilience	Sensitivity
Genetic modification & translocation of indigenous species	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

This pressure is not relevant to the characterizing species within this biotope. Therefore, an assessment of 'Not relevant' has been given.

Introduction or spread of invasive non-indigenous species	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No alien or non-native species are known to compete with *Lophelia pertusa* or other cold-water corals. As a result, a sensitivity assessment of 'No relevant' has been recorded.

Introduction of microbial pathogens	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No information on diseases was found. However, the parasitic foraminiferan *Hyrrokkin sarcophaga* was reported growing on polyps of *Lophelia pertusa* in aquaria (Mortensen, 2001). The foraminiferan dissolves a hole in the coral skeleton and invades the polyp. In his aquaria, two

Lophelia pertusa polyps became infested but did not seem to be influenced by the infestation (Mortensen, 2001). Any parasitic infestation is likely to reduce the viability of the host, even if only a few or possibly hundreds of polyps were affected but in the absence of additional evidence, an assessment of 'No evidence' has been given.

Removal of target species	High	High	Not sensitive
	Q: Medium A: Medium C: Medium	Q: Medium A: Medium C: Medium	Q: Medium A: Medium C: Medium

Lophelia pertusa is not directly targeted by a commercial fishery. However, with the advent of deep water fisheries, the habitats within which *Lophelia pertusa* is found have been heavily targeted by deep-water fishing trawlers because of their high biodiversity. None of the species that are targeted by the commercial fishery have known symbiotic relationships. The only known species with which *Lophelia pertusa* has a symbiotic relationship with is the polychaete *Eunice norvegica* (Mueller *et al*., 2013).

Sensitivity assessment. The biological impact of the removal of species associated with *Lophelia pertusa* is not thought to have a negative impact on this biotope. Consequently, resistance and resilience are assessed as 'High', resulting in a sensitivity assessment of 'High'.

Removal of non-target species	None	Very Low	High
	Q: High A: High C: Medium	Q: High A: Medium C: High	Q: High A: Medium C: Medium

Extraction of *Lophelia pertusa* colonies from the reef would result in fragmentation of the coral, and destruction of the reef structure. The development of larger vessels and more powerful trawls, e.g. rockhopper gear designed to operate on rough stony bottoms, has probably exposed the reefs to increased impacts from fishing (Fosså *et al*., 2002; Fosså, 2003). For example, the fishery of the continental break targeted Greenland halibut, redfish, and saithe. The orange-roughy is another valuable deep-sea species associated with offshore banks, pinnacles and canyons with strong currents, which are favoured by *Lophelia pertusa* (Rogers, 1999). In the UK, monkfish is a major fishery in the vicinity of the *Lophelia pertusa* reefs around Rockall (Dr Jason Hall-Spencer, pers comm.).

Demersal fishing operations have been shown to have a significant negative impact on *Lophelia pertusa* reefs within the North-east Atlantic. Unequivocal evidence for the physical damage of bottom trawling in cold-water habitats has been presented for many areas around the world (Roberts *et al*., 2009), including areas within the North East Atlantic. Fosså *et al*. (2002) used remotely operated vehicles to survey areas of cold-water coral reefs off the west coast of Norway. They described areas historically known cold-water coral reefs, containing *Lophelia pertusa*, to show only scattered coral fragments or crushed and broken coral skeletons. When their findings were extrapolated it was estimated that between 30 – 50% of *Lophelia pertusa* reefs from Norway had been damaged by trawling (Fosså *et al*., 2002). Hall-Spencer *et al*. (2002) found that cold-water coral reefs containing *Lophelia pertusa* off the West Ireland continental shelf break were being damaged by commercial trawls for deep-water fish. Coral aged to be at least 4500 years old, was being removed from reefs as by-catch. Grehan *et al*. (2004) collected imagery data from cold-water coral reefs containing *Lophelia pertusa* off the West Ireland continental shelf break and West Norway. They found widespread damage caused by trawling to cold-water coral reefs within these geographical areas.

Trawling can also re-suspend seabed sediments and cause further damage to the habitat through

smothering (see smothering pressure). Trawling experiments in the Mediterranean found that water-column turbidity increased by as much as three times for five days after a trawling event (Palanques *et al.*, 2001; taken from Roberts *et al.*, 2009). No evidence was available on the impact of re-suspended sediment caused by trawling, the radius of its effects on *Lophelia pertusa*, or the effects on the associated species.

Sensitivity assessment. Removal of a large percentage of the characterizing species would alter the character of the biotope. The resistance to removal is 'None' due to the easy accessibility of the biotopes location and the inability of these species to evade collection. The resilience is 'Very low', with recovery only being able to begin when the harvesting pressure is removed altogether. This gives an overall sensitivity score of 'High'.

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