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REVIEW

Lophelia pertusa conservation in the North Sea using obsolete offshore structures as artificial reefs

Paulina Bergmark, Dolly Jørgensen*

Department of Ecology & Environmental Science, Umeå University, 90187 Umeå, Sweden

ABSTRACT: Deep-water coral reefs are classified as vulnerable marine ecosystems, with trawling identified as the primary cause of reef destruction. *Lophelia pertusa* is the main reef-building species in deep-water coral reefs. In addition to occurring on natural hard substrates, the species has been previously observed on standing offshore oil and gas structures in the North Sea. In this study, we review the available published information about *Lophelia* growth on standing offshore oil and gas industry structures in the North Sea. We discuss the potential uses of obsolete offshore structures repurposed as artificial reefs for targeted *Lophelia* habitat. Our survey of previous studies indicates that artificial reefs created from obsolete structures have a strong potential to form *Lophelia* reef communities similar to those found on natural substrates, although the absence of the polychaete worm *Eunice norvegica* poses some concerns about the completeness of the coral communities that develop on artificial reef structures.

KEY WORDS: Artificial reefs · Coral reef · Cold-water corals · *Eunice norvegica* · Offshore oil platforms · North Sea

INTRODUCTION

Deep-water corals are found in all oceans of the world (Freiwald & Roberts 2005) but grow mainly on the edges of continental shelves, slopes, canyons, seamounts and ridge systems (Roberts & Cairns 2014). Deep-water corals differ from tropical shallow water corals in that they are azooxanthellate, meaning they lack symbiosis with dinoflagellates because of the absence of light in deep waters. Although there are many deep-water coral species, only few are reef-forming, with *Lophelia pertusa* being the main reef-building species. The scleractinian coral *L. pertusa*, the only species in the genus *Lophelia*, is frequently reported on the shelf edge and offshore banks of the northeast Atlantic (Roberts 2002) and thrives in waters with an average temperature of between 6 and 8°C at depths between 200 and 1000 m (Fosså et al. 2002). It is known to form expansive reefs as well as huge carbonate mounds up to 300 m high (Roberts et al. 2006). The largest known *Lophelia* area is the Røst reef southwest of Lofoten Archipelago, northern Norway, with an area of 300 km^2 (Costello et al. 2005).

Cold-water corals are 3-dimensionally complex habitats harbouring thousands of invertebrate and vertebrate species in the NE Atlantic (Roberts et al. 2006), and studies of seamounts in the SW Pacific indicate that species endemism is high in those regions (de Forges et al. 2000). Of the 1482 known scleractinian corals, >41% occur at depths deeper than 50 m (Cairns 2007). Costello et al. (2005) found 25 fish species at deep-water reef sites, including 17 of commercial importance, indicating that deep-

*Corresponding author: dolly@jorgensenweb.net

water coral reefs are important habitats for fish as well as other marine organisms. There are greater fish densities on reefs than in areas with soft- or hard-ground substrate (Purser et al. 2013).

Deep coral reefs are known to be good fishing grounds, and for centuries, fishermen have used nets and long-lines in the vicinity of the corals when fishing (Husebø et al. 2002). Although long-line and gill-net fishermen usually do not do significant damage to the corals (Pham et al. 2014), many reefs have been exposed to trawling which has caused great damage to corals. Fosså et al. (2002) estimate that around 30 to 50% of *Lophelia* reefs in Norwegian waters have been destroyed. The damage may be even more extensive: a report by ICES (2002) states that trawling is very widespread in *Lophelia* areas and that the fraction of reported damaged reefs is minute given how widespread trawling has been and the number of potentially suitable habitats for corals in the Northeast Atlantic waters. Further, the ICES (2002) report expresses serious concerns about the future establishment of *Lophelia* reefs; trawling not only damages the corals themselves but also destroys the bottom habitat by altering the hydrodynamic and sedimentary processes.

Lophelia reefs are habitats that qualify as vulnerable marine ecosystems under United Nations General Assembly Resolution 61/105 and are classed as 'threatened and/or declining species and habitats' under the OSPAR convention for the Protection of the Marine Environment of the Northeast Atlantic 1992 (Ross & Howell 2013). To date, 24 areas with known *Lophelia* occurrences have been closed to fishing in the OSPAR area, covering a total of ~578 000 km^2 (OSPAR Commission 2009).

In addition to fishing, the North Sea is home to oil and gas reserves with >1000 oil and gas platforms offshore all around the North Sea region (Jørgensen 2012a). Approximately 600 structures are in the northern North Sea, defined as north of the Dooley current (Turrell 1992) (Fig. 1). Offshore drilling is often associated with causing environmental damage, but the steel structures themselves have been shown to act as suitable substrata for many fouling species, including *L. pertusa* in the northern area of the North Sea (Roberts 2002, Gass & Roberts 2006, Guerin et al. 2007). The potential to create artificial reefs from disused structures, termed rigs-to-reefs, has recently been suggested as a potentially ecologically beneficial practice worldwide (Macreadie et al. 2011). Although conversion of obsolete oil and gas structures into artificial reefs has been practiced in the Gulf of Mexico for nearly 30 yr (Kaiser & Pulsipher 2005), no conversions have been made in the North Sea (Jørgensen 2012a); thus, no post-conversion structures in the North Sea are available to study.

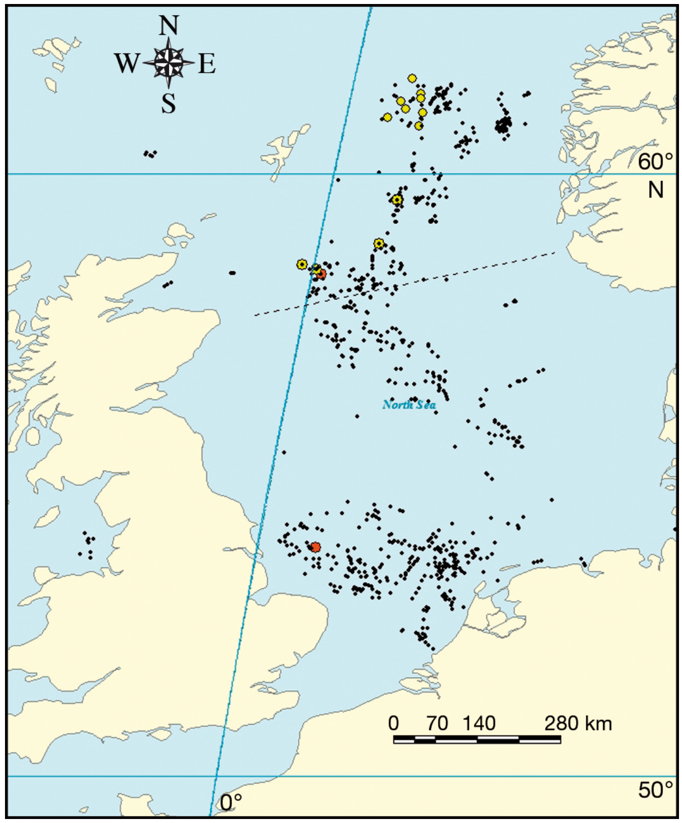

Fig. 1. Distribution of offshore installations (dark dots) in the North Sea and installations with known *Lophelia* occurrence (yellow dots). Red dots represent scientifically investigated installations with no *Lophelia* occurrence. All installations above the dashed line, which is based roughly on the location of the Dooley current, are situated in the northern North Sea

Rigs-to-reefs has proved a contentious concept in the North Sea, primarily due to its association with ocean dumping in the wake of protests against the disposal of the Brent Spar facility at sea (Baine 2002, Jørgensen 2012b). The decommissioning rules of OSPAR, the main international treaty organization for the North Sea, require almost all structures to be taken to shore for disposal, with derogations only for exceptionally large ones (OSPAR Decision 98/3). However, Decision 98/3 excludes structures which are 'serving another legitimate purpose in the maritime area', which could apply if the structures are repurposed as legitimate artificial reef material. In addition to its offshore disposal rules, OSPAR has issued another document relevant to artificial reef creation: 'Guidelines on Artificial Reefs in Relation to Living Marine Resources' (OSPAR Agreement 2012-03, www.ospar.org). This guidance document, which was heavily influenced by the Brent Spar debate, allows only virgin materials in artificial reef construction (Jørgensen 2012a). The document's form as guideline rather than rule means, however, that countries are not legally obligated to follow it; in addition, Norway has never agreed as a signatory to the guidelines. In sum, the creation of artificial reefs from offshore structures might be legally feasible in the North Sea, but because of the current mental association with dumping, such re-purposing could prove politically challenging (Jørgensen 2012a,b). Exposing the potential ecological benefit of artificial reefs constructed from disused offshore structures in the North Sea might help shift perceptions about the practice.

In this study, we review all available published information about *Lophelia* on standing offshore oil and gas industry structures in the North Sea and then discuss the potential uses of artificial structures as targeted *Lophelia* habitat. We focus exclusively on the invertebrate communities; the presence or absence of fish and mammals around the structures are not addressed in this review.

LOPHELIA COLONIZATION OF STANDING STRUCTURES

Lophelia was first noticed on a platform during the dismantling of the Brent Spar bouy and was observed around the Beryl Alpha field in the North Sea by Roberts (2002). Roberts (2002) found a total of 133 colonies of *Lophelia* during a single brief survey of just a small part of each structure, meaning the colonization of *Lophelia* is probably much larger than it has been reported for the Beryl Alpha field. *Lophelia* was found at 13 of 14 oil platforms that were examined in the northern North Sea (Gass & Roberts 2006). All structures with *Lophelia* are located in the northern North Sea (Fig. 1).

There was no relationship between colony size and depth (Gass & Roberts 2006). During the summer stratification, a thermocline is created at ~50 m water depth, which was basically the minimum depth for the occurrence of *Lophelia* in this study. Roberts (2002) studied the videos produced during the routine visual inspection of riser pipes that carry oil from the seabed at the Beryl Alpha field in the North Sea and found colonies of *Lophelia* within the depth range of 75 to 114 m. Gass & Roberts (2006) found similar ranges of *Lophelia*, from 47 to 118 m.

Lophelia colonies on standing platforms serve several functions. Guerin et al. (2007) suggested that the thick growth of *Lophelia* on studied platforms provides habitat space for unknown quantities of small interstitial fauna, which may represent a potential food resource for local fish and motile invertebrates. Because they become de facto no-trawling zones, platforms also provide a refuge for corals and other epifaunal organisms that settle after the structure's installation (Roberts 2002).

Fouling studies show that once oil and gas structures are installed in the North Sea, they quickly become colonized by a diversity of life, turning into complex ecosystems in just a few years (Forteath et al. 1982, Roberts 2002, Guerin et al. 2007). The presence of *Lophelia* as large colonies on the structures indicates that the structures are providing adequate hard habitat for larval attachment and are supporting associated invertebrate fauna.

Many other invertebrate species have been identified on standing structures. Forteath et al. (1982) published the most detailed study of invertebrate communities at platforms, listing all the species that were found during the ROV inspection of the Montrose Alpha facility in the North Sea: 45 species were identified, of which 35 were invertebrates, including 8 phyla: Porifera, Cnidaria, Endoprocta, Annelida, Crustacea, Mollusca, Bryozoa and Echinodermata. The highest number of species belonged to the phyla Bryozoa and Cnidaria.

The soft coral *Alcyonium digitatum* and the anemone *Metridium senile* are 2 of the most common species observed at oil and gas platforms (e.g. Roberts 2002, Whomersley & Picken 2003, Guerin et al. 2007, Moen & Svensen 2009), yet they have not been reported from natural *Lophelia* reefs. Mortensen & Fosså (2006) sampled offshore and inshore *Lophelia* reefs along the Norwegian coast and recorded 361 taxa; *A. digitatum* and *M. senile* were not found among these samples. The failure to find them does not mean these two species do not inhabit cold-water coral reefs, but they are not a common attribute at natural *Lophelia* reefs. It should be noted that Mortensen & Fosså (2006) collected most of their samples from depths between 145 m and 275 m, whereas *A. digitatum* and *M. senile* naturally inhabit shallower waters up to 150 m (Christian et al. 2010). If artificial reefs are created at depths over 100 m, these two species will not dominate as they do on currently standing structures.

Polychaete worms (tubeworms) are known to be one of the most species-rich groups of organisms that inhabit natural *Lophelia* reefs and play a dominant role in both diversity and abundance on cold-water coral reefs in the NE Atlantic (Fiege & Barnich 2009). To date, 116 species of polychaete worms have been recorded from natural *Lophelia* reefs (Mortensen & Fosså 2006). Polychaete worms together with calcareous bryozoans are highly abundant on some platform legs, occurring in the same depth range as *L. pertusa* and *M. senile* (Guerin et al. 2007). Forteath et al. (1982) mentions 2 polychaete worm species, *Pomatoceros triqueter* and *Hydroides norvegica*, both scattered over the steel structure at the Montrose Alpha platform, reaching their greatest abundance below 71 m.

An essential difference between natural *Lophelia*-based reefs and *Lophelia* on standing structures is the absence of the polychaete worm *Eunice norvegica* at offshore oil and gas structures. This tubeworm is associated with *Lophelia*, and the relationship between them has both parasitic and mutualistic elements and can be regarded as a non-obligate mutualism (Mortensen & Fosså 2006). The tubeworm plays an important role in the growth of *Lophelia* reefs by enhancing coral calcification up to 4-fold; *E. norvegica* assimilated 2 to 4 times more food in the presence of the coral, and the tubeworm helps to clean sediments from the coral's polyps (Mueller et al. 2013). The absence of this tubeworm on standing structures is mentioned by both Roberts (2002) and Gass & Roberts (2006). It is not known why *E. norvegica* does not exist at offshore structures while other polychaete worm species do occur. More studies of the biology and ecology of *E. norvegica* are needed to conclude why this species is not currently found at offshore oil and gas structures in the North Sea.

POTENTIAL OF ARTIFICIAL REEFS AS NORTH SEA *LOPHELIA* HABITAT

Given the fact that complex invertebrate communities establish at offshore oil and gas platforms shortly after their installation (Sammarco et al. 2004), these steel structures offer suitable substrates for a variety of marine species. The habitat created by an artificial reef will depend on how the reef structure is laid out. In the Gulf of Mexico, for example, Sammarco et al. (2014) found that although the overall coral density of standing and toppled platforms was not statistically different, individual species densities changed with toppling. The conclusion is that there are differences in community structures between standing platforms (as discussed in the previous section) and intentionally created artificial reefs that are at greater depths. Thus, in the North Sea, we can expect changes in the community when artificial reefs are created.

By studying the occurrence of fouling species on the North Sea platforms, scientists have recognized that marine growth is often depth related, each zone being dominated by a different group of organisms. Forteath et al. (1982) recognized 5 such zones, with seaweeds dominating the sunlit shallow zone down to 10 m, hydroids and arborescent bryozoans dominating the shaded zones down to 31 m, calcareous bryozoans dominate in the depth range between 31 and 51 m, encrusting bryozoans between 51 and 71 m and aggregate tubeworms and deep-water barnacles between 71 and 91 m. By toppling the platforms to allow for the required shipping clearance of 55 m (IMO 1989), a different community structure will establish compared to the community structure on standing platforms, because no substratum will be available in the upper zone. Species that today are frequently reported from platforms, such as the soft coral *A. digitatum* and the anemone *M. senile*, inhabit shallower waters, so would not be present on a deeper artificial reef. Toppling the platforms will also enhance *Lophelia* colonization of the whole structure due to increased structure area at suitable depths, and the coral will no longer be limited by bathymetrical factors such as the thermocline.

There is a question as to whether or not a platform should be toppled in place because of drill cuttings. Studies of drill cutting piles (e.g. Breuer et al. 2004, Gass & Roberts 2006, Breuer et al. 2008) indicate a risk of contamination by heavy metals in the cuttings. This is of particular concern to communities living close to or on drill cutting piles. By relocating structures as intentionally created artificial reef habitats to areas with no drill cutting piles, the risk of contamination will be minimized.

It has to be put in perspective that natural *Lophelia* reefs have been shaped over thousands of years, forming complex and extremely diverse habitats. The communities found at platforms are newly established, and it may take years before such reefs will resemble natural reefs of deep waters. Hiscock et al. (2010) studied the colonization of a steel wreck in Whitsand Bay, south Cornwall, over a period of 5 yr and found that 'the artificial reef developed a community that was distinctly different to nearby natural rock reefs'. Perkol-Finkel et al. (2006) compared the community structure on a 119 yr old shipwreck to a neighbouring natural reef in the Red Sea and concluded that an artificial reef will mimic its adjacent natural reef community only if the artificial reef possesses structural features similar to those of the natural surrounding. Studies have shown a growth rate between 6 and 26 mm yr^{-1} for corals on North Sea platforms (Gass & Roberts 2006) and a minimum growth rate ranging from 32 to 323 mm for corals on platforms in the Gulf of Mexico (Larcom et al. 2014). Even natural *Lophelia* reefs vary greatly in species composition; thus, it cannot be expected that the rigs' communities will be identical to natural deep-water reefs.

The most obvious omission from the artificial community is the polychaete worm *E. norvegica*. Because no individuals of this species have been observed at platforms to date, *E. norvegica* may be initially absent from artificial reefs in the North Sea. The absence of *E. norvegica* might limit optimum *Lophelia* reef community development on purposefully created artificial reefs made of obsolete offshore structures, but it should also be seen as an opportunity to further study the relationship between these 2 species and to what extent this symbiosis affects the development of a reef. One option could be to relocate *E. norvegica* adults within parts of the restoration zone to study differences between reef sites where *E. norvegica* exists and where it is absent. It could also be that the worm will naturally recruit after several decades of reef development.

CONCLUSIONS

Our survey of the previous studies conducted at offshore oil and gas platforms in the North Sea indicates that artificial reefs created from obsolete structures have a strong ecological potential to form *Lophelia* reef communities in the northern North Sea. A reef complex in the northern North Sea, which could be constructed of structures relocated from anywhere in the North Sea, might offer protection to local fish communities. A designated protected reef zone could exclude trawling and give fish a refuge as long as they stay close to the reef zone, reducing the fishing pressure on local fish communities. A protected zone could also boost total fish populations in the area.

It is important to note that artificial reef creation should not be seen as a substitute for restricting trawling on natural reefs. The first priority has to be to protect existing *Lophelia* reefs to avoid further damage to these vital ecosystems. Artificial reefs should be seen as a complement to natural protected areas and might also give important knowledge of the process of reef formation in deep dark waters.

Although artificial reefs have potential as coral conservation sites in the North Sea, rigs-to-reefs is still controversial because it involves reusing structures from an industry mostly associated with causing environmental damages. This study has focused on the biological potential of rigs-to-reefs to be used as a targeted *Lophelia* reef conservation measure in the North Sea but has not addressed the technical, economic or social aspects of the practice that require formalization and implementation. In order to move an artificial reef program in the region forward, integrated discussions of both scientific and social factors will be required. It is hoped, however, that this review shows that obsolete offshore structures could be valuable artificial reef substrate in the North Sea from an ecological perspective.

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