First description of a *Lophelia pertusa* reef complex in Atlantic Canada

Pål Buhl-Mortensen[a,*], Don C. Gordon Jr.[b], Lene Buhl-Mortensen[a], Dave W. Kulka[c]

[a] Institute of Marine Research, PO Box 1870 Nordnes, N-5817 Bergen, Norway
[b] Bedford Institute of Oceanography, PO Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2
[c] Dartmouth, Nova Scotia, Canada

ARTICLE INFO

ABSTRACT

For the first time, we describe a cold-water coral reef complex in Atlantic Canada, discovered at the shelf break, in the mouth of the Laurentian Channel. The study is based on underwater video and sidescan sonar. The reef complex covered an area of approximately 490×1300 m, at 280–400 m depth. It consisted of several small mounds (< 3 m high) where the scleractinian *Lophelia pertusa* occurred as live colonies, dead blocks and skeletal rubble. On the mounds, a total of 67 live colonies occurred within 14 patches at 300–320 m depth. Most of these (67%) were small (< 20 cm high). Dead coral (rubble and blocks), dominated (88% of all coral observations). Extensive signs of damage by bottom-fishing gear were observed: broken and tilted coral colonies, over-turned boulders and lost fishing gear. Fisheries observer data indicated that the reef complex was subjected to heavy otter trawling annually between 1980 and 2000. In June 2004, a 15 km^2 conservation area excluding all bottom-fishing was established. Current bottom fisheries outside the closure include otter trawling for redfish and anchored longlines for halibut. Vessel monitoring system data indicate that the closure is generally respected by the fishing industry.

1. Introduction

Cold-water corals have been reported from many offshore locations in Atlantic Canada (Verrill, 1922; Deichmann, 1936; Zibrowius, 1980; Breeze et al., 1997; MacIsaac et al., 2001; Mortensen and Buhl-Mortensen, 2004; Gass and Willison, 2005; Mortensen and Buhl-Mortensen 2005a, Mortensen et al., 2006; Wareham and Edinger, 2007; Cogswell et al., 2009; Edinger et al., 2011). Sources of data include records of bycatch from fisheries, fishers' observations (traditional ecological knowledge), as well as scientific studies. Cold-water corals are most abundant in channels, canyons and along the edge of the continental slope in the depth range of 200–1500 m. To date, 31 species of corals including soft corals (Alcyonacea), gorgonian corals (Gorgonacea), stony corals (Scleractinia), and black corals (Antipatharia) have been recorded off Atlantic Canada (Mortensen et al., 2006; Wareham and Edinger, 2007; Cogswell et al., 2009; Baker et al., 2012) of which eight are scleractinians. Including sea pens, this number would be closer to 50. Despite the relatively high number of species, there are few known areas where corals form habitats such as reefs or gardens. One such area is the hard bottom coral gardens in the Northeast Channel, between Georges Bank and Browns Bank (Fig. 1), which have been studied using visual observation techniques (Mortensen and Buhl-Mortensen, 2004; Mortensen et al., 2005; Watanabe et al., 2009;

Bennecke and Metaxas, 2017).

L. pertusa is a long-lived, reef-building, cold-water scleractinian found worldwide, and it is the major reef-forming coral in the North Atlantic (Davies and Guinotte, 2011; Buhl-Mortensen et al., 2015). The greatest density of reefs known so far has been found along the Norwegian coast where they have developed since the end of the last glaciation (Mortensen, 2000; López-Correa et al., 2012; Buhl-Mortensen et al., 2015). However, several other North Atlantic regions such as the Faroe Plateau, and the Rockall and Porcupine Banks have prominent reef occurrences (Wheeler et al., 2007), and recently a *Lophelia* reef was discovered off the southern west coast of Greenland (Kenchington et al., 2016). Many environmental factors (i.e. temperature, salinity, water velocity, substratum type and food availability) are important in controlling its distribution (Strømgren, 1971; Frederiksen et al., 1992; Freiwald et al., 1999; Mortensen et al., 2001; Dodds et al., 2007; Dullo et al., 2008). Topography has proven useful for predictive modelling of the distribution of *L. pertusa* because food supply, bottom currents and substratum to a large extent are related to topography (Mohn et al., 2014). *L. pertusa* is a broadcast spawner with long larvae stage and dispersal range (Brooke and Järnegren, 2013; Larsson et al., 2014). Under favourable conditions, *L. pertusa* can form reefs that are tens of meters tall and hundreds of meters long, offering a wide range of habitats to other organisms (Mortensen et al., 1995; Wheeler et al., 2007).
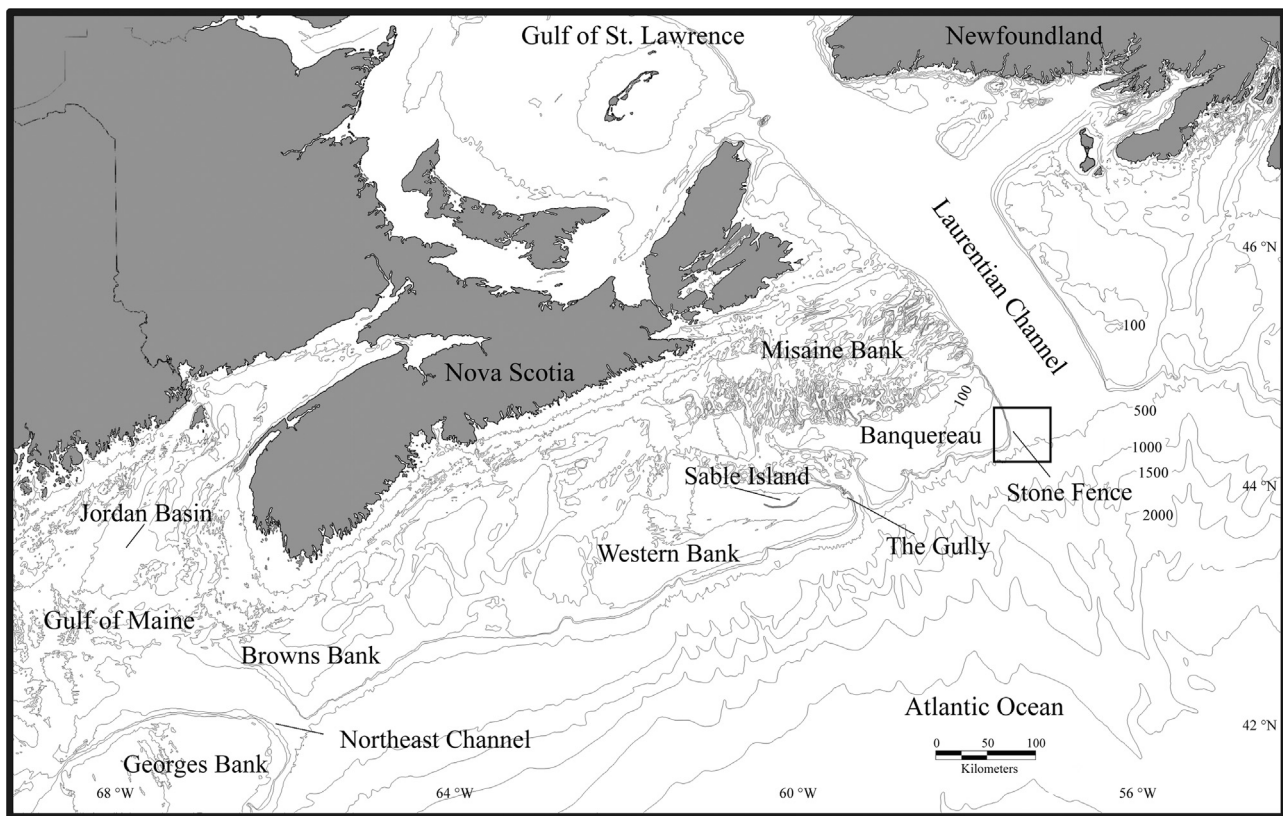
Fig. 1. Regional map outlining the location of the study area in Atlantic Canada. The box outlines the area shown in Fig. 2.

The skeletons of *L. pertusa* provide habitats for a highly diverse fauna of invertebrates (Jensen and Frederiksen, 1992; Mortensen and Fosså, 2006; Henry and Roberts, 2007; Buhl-Mortensen et al., 2010) and commonly reefs have been found to have a higher abundance of fish compared to the adjacent seabed (Mortensen et al., 1995; Husebø et al., 2002; Costello et al., 2005). *L. pertusa* reefs and associated gorgonians are easily damaged by bottom-contacting fishing gear (Fosså et al., 2002; Krieger, 2001; Mortensen et al., 2005). The recovery of these damaged habitats is slow due to low growth rates (Mortensen and Rapp, 1998; Gass and Roberts, 2006), and physical damage is likely to have serious negative consequences on local biodiversity and fish abundance. Fishers in Atlantic Canada have reported bycatches of *L. pertusa* skeletons from several locations, most notably in The Gully, a submarine canyon east of Sable Island, a Marine Protected Area since 2004 (Fig. 1) (Breeze et al., 1997; Gass and Willison, 2005). One piece of *L. pertusa* skeleton was collected in this area during groundfish surveys conducted by the Canadian Department of Fisheries and Oceans (DFO) (G. Pohle, personal communication). Mortensen and Buhl-Mortensen (2005a) report an observation of a possibly living colony from The Gully. There is also an observer report of *L. pertusa* in the Jordan Basin in the Gulf of Maine (Fig. 1), as well as a specimen deposited with the Nova Scotia Museum of Natural History reported to have been collected in one of the "holes" on Misaine Bank, around 160 km northwest of Stone Fence (Fig. 1) (Cogswell et al., 2009).

In 1997, DFO began conducting coral surveys in Atlantic Canada using non-destructive imaging equipment. In 2002, during surveys in the Laurentian Channel region, a few live *L. pertusa* fragments were observed near the Stone Fence (Fig. 1). This was the first time that live *L. pertusa* had been directly observed in Atlantic Canada in its natural habitat. This site was revisited in 2003 to provide more details on the distribution and abundance of *L. pertusa*.

Here, we describe the observations made in 2002 and 2003 of the *L. pertusa* reef complex in the mouth of the Laurentian Channel including its spatial extent, morphology (structure and habitat features), health of

colonies and associated coral and fish taxa. Findings are compared with the historical fishing effort in the area, and possible impact of bottom fishing on the reef complex is discussed. Finally, the conservation area established by DFO in 2004 to protect the reef complex from further damage and promote recovery is described.

2. Description of the study area

The Laurentian Channel is a glacial trough which separates the Scotian Shelf from the Grand Banks of Newfoundland and connects the Gulf of St. Lawrence to the Atlantic Ocean (Fig. 1). The Stone Fence is situated along the eastern edge of Banquereau at the mouth of the Laurentian Channel. The seabed is characterized by glacial deposits with sand and gravel (Fader et al., 1982; Mosher and Piper, 2007). Sand waves have also been mapped in this area indicating periodic high currents and sediment transport (Fader et al., 1982). An abundance of boulders along the Stone Fence led to its naming by local fishers. The fishing captain J. W. Collins reported that the Stone Fence and the eastern slope of Banquereau had the greatest abundance of corals (the gorgonians *Keratoisis ornata, Paragorgia arborea* and *Acanella arbuscula*) of any of the outer fishing banks (Collins, 1884).

The water masses of the Laurentian Channel are highly stratified, and the general hydrography of the area has been described by Lauzier and Trites (1958) and Han et al. (1998). Below approximately 250 m, there is a warm saline bottom layer with temperatures generally between 4 and 8 °C and salinity higher than 34 psu. The Channel permits deep-water incursions from the Atlantic Ocean into the Gulf of St. Lawrence, which are balanced by the outflow of the estuarine water from the Gulf of St. Lawrence in the upper layer. The primary factor determining deep-water properties in the Laurentian Channel is the variation of incoming oceanic waters rather than variation of freshwater runoff. The inflow to the Gulf of St. Lawrence occurs mainly on the eastern side of the Channel, whereas the outflow mainly occurs on the western side.
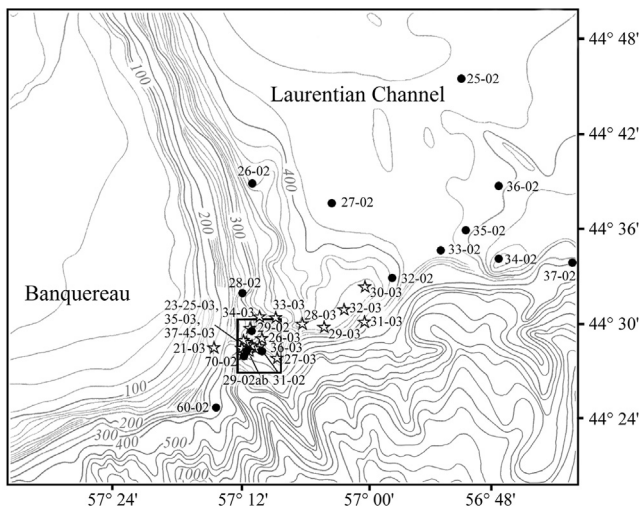
Fig. 2. Location of Campod transects surveyed for cold-water corals at the mouth of the Laurentian Channel near the Stone Fence. Closed circles indicate 2002 surveys, stars 2003 surveys. The box outlines the area shown in Fig. 4.

The Stone Fence has been subjected over the years to a relatively intense fishery involving both mobile and fixed gears (Breeze and Horsman, 2005). Since 1977, trawlers have accounted for 70–75% of the groundfish landings from this area and longliners most of the rest (Fisheries Resource Conservation Council, 2002). The cod (*Gadus morhua*) and haddock (*Melanogrammus aeglofinus*) fisheries were closed in 1993 due to the crash in stocks. Today, redfish (*Sebastes* spp.) and halibut (*Hippoglossus hippoglossus*) are the most commonly targeted groundfish within the study area, fished with otter trawls and demersal longlines, respectively.

3. Material and methods

3.1. Selection of Study Sites and Imaging of the Seabed

In total, 40 sites were surveyed at the mouth of the Laurentian Channel by the C CG S *Hudson* using Campod, a tethered video/still camera platform (Gordon et al., 2000, Fig. 2). The camera set-up consisted of: a Sony XC-999 colour video camera mounted obliquely to provide a forward-looking, wide-angle view while drifting over the seabed. A downward looking Sony 3-CCD high-resolution video camera mounted on the central axis of the frame, providing wide-angle, zoom and macro adjustment to allow both broad coverage and close inspection of the seabed. Illumination for the video cameras was provided by a pair of 500 W quartz halogen lights. A 35 mm Nikon F4 still camera (with a 250 exposure film pack) and two high speed flashes (Quantum Q powered by turbo-batteries) were also mounted on the frame.

These survey sites were selected in areas with seabed topography most likely to support corals (i.e. at spurs and ridges along the shelf edge at depths in the range of 200–500 m). The video transects covered a depth range of 195–500 m while transect length ranged from 200 to 3500 m and averaged about 1000 m (Table 1). The total distance surveyed was 39,910 m within an area of approximately 1000 km^2. In September 2002, 16 transects were run on CCGS *Hudson* cruise HUD2002-054, and 24 transects in September 2003 on CCGS *Hudson* cruise HUD2003-059 (Table 1). Surveys were limited to depths < ~500 m because of Campod cable length. Information from fishers (Gass and Willison, 2005), earlier Campod observations in the area (MacIsaac et al., 2001) and bathymetric data were used to help select transect locations. The ship was allowed to drift while Campod was deployed so that large areas of the seabed could be surveyed. Campod was equipped with a hydroacoustic navigation system (ORE Trackpoint II ultra-short baseline navigation system) to provide a record of its track over the seabed. The positions were quite noisy, with an error in the

order of ± 5 m, but after filtering the data the error was reduced to ± 2 m. Bathymetric data from the ship's echo sounder were logged at one second intervals. Bathymetrical data were also gathered from previous CCGS *Hudson* cruises to the study area. No multibeam sonar data is available from this region, although the GSC Laurentian Fan west data comes close, it stops at about the 500 m isobath.

3.2. Video analysis

The twenty-two hours of video footage collected were analysed in the laboratory. Patches of L. *pertusa* were noted, georeferenced and categorized as living colonies or fragments (LL), skeletal rubble (LR = small fragments of dead skeleton) or dead blocks (DL = dead skeleton fragments larger than about 20 cm). Live *L. pertusa* is bright, white or pink and easy to distinguish from dead darker, grey or brown skeleton. Quantification of rubble (LR) and dead blocks (DL) within patches was difficult and not attempted, but individual live colonies within patches were easily counted. These were divided into two size groups: small (less than about 20 cm), and large (larger than about 20 cm). Examples of these three different forms of *L. pertusa* are illustrated in Fig. 3.

The percent cover of substrate types (i.e. sand, pebble, cobble and boulder) was roughly estimated at regular intervals along transects following the size classes as defined by the Wentworth scale (Wentworth, 1922). The occurrence of other coral species and redfish along the transects was recorded and their abundance calculated in units of individuals (or colonies) per 100 m^2. Signs of fishing activity were also recorded (broken and tilted corals, over-turned boulders, trawl marks, and presence of fishing gear) as numbers of sightings per 100 m^2.

3.3. Sidescan sonar survey

On June 9, 2003, the Geological Survey of Canada conducted a single sidescan sonar transect across the site where the live *L. pertusa* was observed in 2002 (Fig. 5). This transect provided information on the morphology and general seabed characteristics. The sidescan was set at 120 kHz with a range of 200 m to each side of the centre line.

3.4. Distribution of fishing effort

The spatial distribution of otter trawling fishing effort in the study area was estimated by Kulka and Pitcher (2001). The percentage of the seabed potentially disturbed by otter trawling each year from 1980 to 2000 was calculated using the georeferenced trawl set locations recorded by the DFO Fisheries Observer Program. Since observer coverage was < 100%, data were scaled up to total effort using the ratio of catch from DFO landing statistics to the observed directed catch. For each of 21 years, the locations where trawls contacted > 50% of the bottom was mapped and overlaid, and the spatial distribution of the number of years that the potential trawling disturbance exceeded 50% of the seabed was plotted. More recent data on the distribution of redfish (otter trawl) and halibut (longline) fisheries in the study area were provided by the DFO Oceans and Coastal Management Division from logbook landings data to determine how recent fishing activity relates to the boundaries of the conservation closure.

4. Results

4.1. Spatial distribution of Lophelia pertusa

One occurrence of small, broken but living fragments of *L. pertusa* was observed in 2002 among skeleton rubble at a depth of 317 m on Transect 29b-02 (Table 1). All together (2002 and 2003), 30 patches of skeletal rubble (LR) were observed along 12 transects, 14 patches of live *L. pertusa* (LL) were observed along 8 transects and 12 patches of dead blocks (DL) were found along 7 transects (Table 1). Of all coral

Table 1
Depth and length of Campod transects (2002 and 2003), percentage cover of different substrates, number of patches of *Lophelia* rubble (LR), dead blocks (DL) and live colonies (LL), number of live colonies (LL) in two size categories (< 20 cm and > 20 cm), densities of redfish (individuals per 100 m^2) and sightings of fishing gear (longlines and trawl nets) and trawl marks per 100 m^2.

Transect	Depth (m)	Length (m)	% Sand	% Pebble	% Cobble	% Boulder	*Lophelia* patches LR	DL	LL	Live *Lophelia* colonies (LL) < 20 cm	> 20 cm	Redfish	Longlines	Trawl marks	Trawl nets
25-02	246–256	700	100	0	0	0	0	0	0	0	0	0.1	0	0	0
26-02	357–352	850	97	1	2	1	0	0	0	0	0	0.7	0	0	0
27-02	407–401	950	89	10	1	1	0	0	0	0	0	0	0	0	0
28-02	234–324	1100	73	8	13	5	0	0	0	0	0	0.3	0	0	0
29-02	286–236	550	58	14	16	13	0	0	0	0	0	0.8	0	0	0
29a-02	360–335	800	33	35	24	8	0	0	0	0	0	22.5	0	0	0
29b-02	317	1950	40	21	26	13	5	0	1	3	0	9	0.05	0	0
31-02	379–347	1200	32	35	21	13	0	0	0	0	0	6	0	0	0
32-02	449–473	1300	67	21	10	1	0	0	0	0	0	0.2	0	0	0
33-02	399–404	1150	72	11	12	5	0	0	0	0	0	3.6	0	0	0
35-02	386–385	850	97	1	2	1	0	0	0	0	0	0.5	0	0	0
34-02	368–362	1100	88	4	5	3	0	0	0	0	0	1	0	0	0
37-02	483–464	750	97	1	2	0	0	0	0	0	0	0.6	0	0	0
36-02	390–390	850	98	1	2	0	0	0	0	0	0	0.4	0	0	0
60-02	NA	500	72	12	13	3	0	0	0	0	0	0.5	0	0	0
70-02	412–374	1900	66	15	14	5	0	0	0	0	0	0.2	0	0	0
21-03	370–250	460	40	25	25	10	0	0	0	0	0	0.5	0	0	0
23-03	388–500	800	50	20	20	10	0	0	0	0	0	0.6	0	0	0
24-03	278	1000	40	25	25	10	1	0	1	1	0	0.1	0	0.06	0
25-03	345–502	900	30	30	30	10	1	2	0	0	0	4.4	0	0.06	0
26-03	271–368	3500	25	35	30	10	1	0	0	0	0	3	0.1	0	0
27-03	393	2000	30	30	30	10	0	0	0	0	0	5	0	0	0
28-03	411–359	700	30	30	30	10	0	0	0	0	0	4.9	0	0	0
29-03	389–414	550	55	20	20	5	0	0	0	0	0	9.1	0	0	0
30-03	395–395	900	69	20	10	1	0	0	0	0	0	0.7	0.1	0.1	0
31-03	370–371	1150	59	20	20	1	0	0	0	0	0	6.4	0	0.1	0
32-03	358–358	1000	51	22	22	5	0	0	0	0	0	5	0.05	0.2	0
33-03	329–300	800	51	22	22	5	0	0	0	0	0	6.3	0.06	0	0
34-03	315	850	69	15	15	1	0	0	0	0	0	4.6	0.06	0	0
35-03	303–300	700	69	15	15	1	0	0	0	0	0	2	0	0	0
36-03	345–345	200	55	20	20	5	0	0	0	0	0	0.7	0	0	0
37-03	346–338	450	45	25	20	10	0	0	0	0	0	0.7	0.1	0.1	0
38-03	333–400	1500	38	18	33	11	9	2	2	9	2	3.3	0.3	0.06	0
39-03	268–398	2000	54	23	15	8	3	2	2	2	0	3	0.05	0.03	0
40-03	260–363	700	47	23	15	15	1	0	0	0	0	3.1	0	0	0.05
41-03	316–290	700	32	18	20	30	2	1	1	1	0	0	0.05	0	0
42-03	287–345	700	42	23	15	20	2	0	0	0	0	2.8	0	0	0
43-03	261–373	400	35	22	15	28	2	2	3	10	6	5.3	0	0	0
44-03	336–389	950	54	23	15	8	1	2	2	12	9	6.4	0.05	0	0
45-03	275–284	500	45	25	20	10	2	1	2	8	4	6.2	0	0.1	0
Average		998	57	18	17	8	0.8	0.3	0.4	1.2	0.5	3.3	0.02	0.02	0.002
Sum		39,910	–	–	–	–	30	12	14	46	21				
With *Lophelia*	260–502	1233	40	22	20	15	2.4	1	1	3.2	1.6	3.9	0.05	0.03	0
Without *Lophelia*	234–502	38,677	65	16	15	5	–	–	–	–	–	3	0.02	0.02	0

observations, 77% were dead *L. pertusa*. The live *L. pertusa* patches (LL) most commonly included several colony fragments (e.g. 16 live colonies were observed in 3 patches along Transect 43-03). In total, 46 small and 21 large living colonies were observed (Table 1). All sightings of dead blocks and skeletal rubble were made at depths between 280 and 400 m, while most living colonies were observed within a narrow depth range of 300 and 320 m. The spatial distribution of all *L. pertusa* patches, both live and dead (rubble and blocks combined), is plotted in Fig. 4 along with the transect paths. The size of the *L. pertusa* patches, estimated from the navigation data, averaged 84 m and ranged from a few meters to approximately 250 m.

4.2. Reef morphology and habitat

Living *L. pertusa* and dead coral blocks were observed on mounds that were less than 3 m high while skeleton rubble was more widely spread and occurred on mounds as well as on more level bottoms between the mounds. Underneath the corals, the mounds most likely consist of gravel, which was evident at sites where the coral cover was not complete, but in many cases the skeleton rubble covered the underlying seabed. It was not possible to estimate the thickness of the cover of skeletal debris. The largest living colonies were about 1.5 m wide and between 0.5 and 1 m high, but their tops appeared to have been "cut off", exposing older, dead inner parts of the colonies. Most of the living colonies were substantially smaller (about 10–15 cm high). Altogether, these observations indicated the presence of a *L. pertusa* reef complex of considerable size, approximately 490 × 1300 m (about 0.6 km^2).

The bathymetric data collected during the surveys were processed and the interpolated surface is plotted in Fig. 4. The reef complex is located on the inner part of a ridge on the sloping seabed at the shelf break. The substrate along the transects was quite variable reflecting its glacial origin (Table 1). In general, there was a relatively high percentage of hard bottom substrates (pebbles, cobbles and boulders) which can provide a stable substrate for the attachment of corals. The transects with *L. pertusa* had a greater hard bottom coverage (especially for boulder) than those without, whereas the percentage cover of sand was much higher for transects without *L. pertusa* (Tables 1, 2). The

difference (T-test with Two-sample assuming unequal variances) was statistically significant ($p < 0.05$) for all substrates (Table 2). The sidescan sonar transect across the site where the live L. *pertusa* was observed in 2002 (Figs. 4 and 5A and B) showed that the seabed is hard over most of the study area. The sonar image (Fig. 5B) indicates a rugged seafloor with variable backscatter strength, partly overlapping with occurrences of *Lophelia* patches.

4.3. Observations of invertebrates and fish

In addition to L. *pertusa*, seven coral taxa were observed along the 40 transects (Table 3). Only two transects (21-03 and 41-03) had no corals at all. The most abundant taxa were *Duva florida*. (Alcyonacea), *Anthomastus grandiflorus* (Alcyonacea) and *Acanthogorgia armata* (Gorgonacea) while the least abundant were *Flabellum* sp. (Scleractinia) and *Keratoisis ornata* (Gorgonacea). *A. grandiflorus* and *A. armata* were much more abundant along transects without L. *pertusa*. Both *Primnoa resedaeformis* (Gorgonacea) and *Paragorgia arborea* (Gorgonacea) were much more abundant along transects with L. *pertusa*, reflecting their similar habitat requirements (Buhl-Mortensen et al., 2015). Zooanthid anemones dominated in DL and LL areas, where they mainly occurred on larger dead coral fragments or on dead parts of live colonies (Fig. 3A and C).

Redfish (*Sebastes* spp.) were observed along all transects but two (27-02 and 41-03). On average, they were more abundant along transects with L. *pertusa* than those without (Table 1). However, the variation was great and the difference was not statistically significant ($p > 0.05$).

4.4. Damage to corals

Numerous signs of damage were evident within the reef complex. All larger L. *pertusa* colonies were broken, and several were sheared off at the top. The area of rubble was large compared to the area of blocks and live colonies (81% of all observations recorded in the field). Within the rubble patches, grey-white skeletons, probably recently exposed from burial in the sediments (Fig. 3D), were common in addition to the dark brown skeletons with natural manganese coating from aging on the sediment surface (Fig. 3E). As was the case for L. *pertusa*, most colonies of *P. arborea* observed in the reef complex were small (less than 50 cm tall) and many were tilted. Colonies of L. *pertusa* and *P. arborea* were observed attached to the sides of boulders indicating that the boulders had been over-turned sometime in the past. Tilted or broken colonies of *P. resedaeformis* and *K. ornata* were also frequently observed.

While some breakage of old colonies can occur naturally, most of the damage observed on the reef complex clearly appears to have been
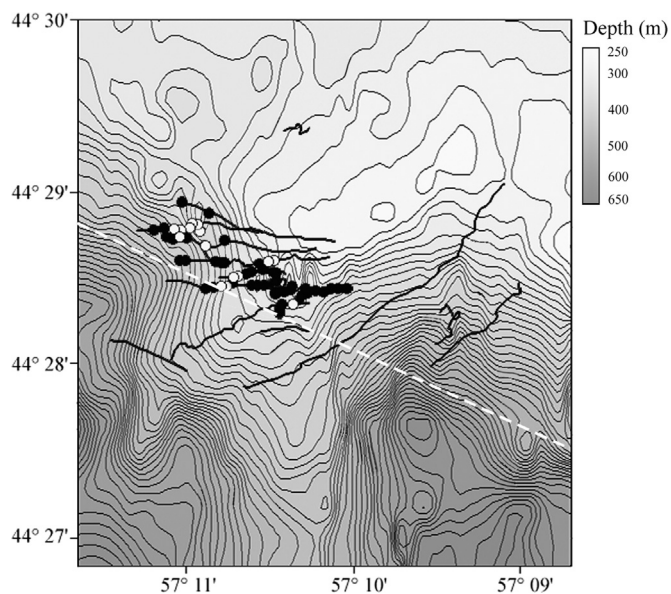
Fig. 4. Location of *Lophelia pertusa* patches observed in the video footage plotted over bathymetric data from single beam echo sounder collected during several surveys to the area. Open circles indicate patches of live *L. pertusa* (LL) while closed circles indicate patches of rubble (LR) and dead blocks (DL). The thick lines indicate the path of Campod transects. The dashed line indicates the location of the sidescan sonar survey line.

caused by fishing activities. Pieces of longline gear were observed along 11 of the 40 transects in the study area (Table 1). What appears to be otter trawl door tracks were observed along 9 of the transects while a piece of otter trawl net was found along one transect. Signs of fishing gear were more abundant along transects that had L. *pertusa* than those without (Table 1). However, the difference was not statistically significant ($p < 0.05$) using a T-test with Two-sample assuming unequal variances.

Quantitative analysis of the observer effort data indicates that the reef complex falls within an area that has been the target of intensive otter trawling since at least 1980 (Fig. 6), mainly targeting redfish. It has been heavily trawled ($> 50\%$ of the seabed potentially disturbed annually) for either 20 or 21 of the 21 years for which data are available (1980–2000). Most of the surrounding area, except that immediately to the northeast, has been disturbed by otter trawling at a lower level (Fig. 6). Observer data from 1998 to 2003 indicates that the mouth of the Laurentian Channel, including the immediate area of the reef complex, had been extensively fished for redfish (*Sebastes* spp.) using otter trawls and halibut (*Hippoglossus hippoglossus*) using anchored longlines. The same effort distribution is also evident in the DFO landings data base (Statistics Br. Fisheries and Oceans). However, records of landings in NAFO Div 4Vs, the statistical division that includes the Stone Fence have greatly diminished since the late 1990s indicating a corresponding reduction in fishing effort in the area. After the mid-2000s, redfish landings from trawls in Div. 4Vs have been stable at about 25% of what was reported in the late 1980s. The reduction for longlined Atlantic halibut was smaller and that fishery has been

increasing in recent years. Indicated by VMS data fishers have largely avoided the closure since its inception (Derek Fenton, DFO, unpublished data).

5. Discussion

5.1. Spatial distribution and the environment

The presence of *L. pertusa* in Atlantic Canada has been known for many years through records from bycatch data, observer reports and interviews with fishers (Zibrowius, 1980; Breeze et al., 1997; Gass and Willison, 2005). Most of these records are from the region of The Gully and Stone Fence but there are also one from the Jordan Basin in the Gulf of Maine, the Northeast Channel, and one of the holes on Misaine Bank (Fig. 1). However, the present-day status of *L. pertusa* remains largely unknown. In 1997, DFO began to conduct annual video surveys in prime coral habitats in Atlantic Canada and it was not until 2002 that the first observation of live *L. pertusa* in its natural habitat was made. Now, with our extensive observations from 2003, we can report the continued presence of a relatively large (about 0.6 km^2) *L. pertusa* reef complex in the mouth of the Laurentian Channel near the Stone Fence. This is the first documented record of such a structure in Atlantic Canada.

This reef complex is composed of numerous mounds which appear to be less than 3 m in height. The horizontal extent of these mounds, up to more than 200 m, is comparable with the size of individual non-coalesced *L. pertusa* mounds off mid-Norway (Mortensen et al., 2001). Living colonies of *L. pertusa* and dead blocks were located on the mounds while the more abundant skeleton rubble was observed on both the mounds and the more level bottom between them. The gorgonians *P. resedaeformis* and *P. arborea* were common on the mounds. In addition, redfish appeared to be more abundant on those transects with *L. pertusa* than without. The reef complex was found between 280 and 400 m in depth while most of the living colonies were restricted to 300–320 m. It is located on a sloping seabed at the shelf break (Fig. 4) in an area with abundant boulders. The net circulation on the western side of the Laurentian Channel is seaward (Han et al., 1998) and it is expected that these waters have a high concentration of organic particles (Roy et al., 2000) that may serve as food for cold-water corals.

The sidescan line (Fig. 5) crossed the southern edge of the area of the extension of the interpreted reef complex. A survey line located approximately 100 m north of this line would probably provide a better graphical representation of reef structures. The distribution of *L. pertusa* in the study area could be more extensive than observed in our more spatially restricted video survey. Based on the surficial geology map of Fader et al. (1982), the area of sediment where the *L. pertusa* was found is much larger and could extend the distribution to the northwest along the flank of the Laurentian Channel for a considerable distance.

L. pertusa in Atlantic Canada may be regarded as scattered populations, similar to the isolated colonies seen at about 1000 m depth below the Stone Fence in 2007 (Cogswell et al., 2009), geographically isolated from other areas with more prolific populations. Similarly, along the margin of the northeastern US, the coral has only been observed as isolated small colonies, mainly in canyons (Brooke and Ross, 2014). Off

Table 2
Comparison of percentage coverage of substrate types on video lines with and without *Lophelia pertusa*. *t*-Test: Two-Sample Assuming Unequal Variances. Hypothesized Mean Difference = 0. Video lines without Lophelia: n = 28. Video lines with Lophelia: n = 12. With Bonferroni correction results with P < 0.0125 were significant.

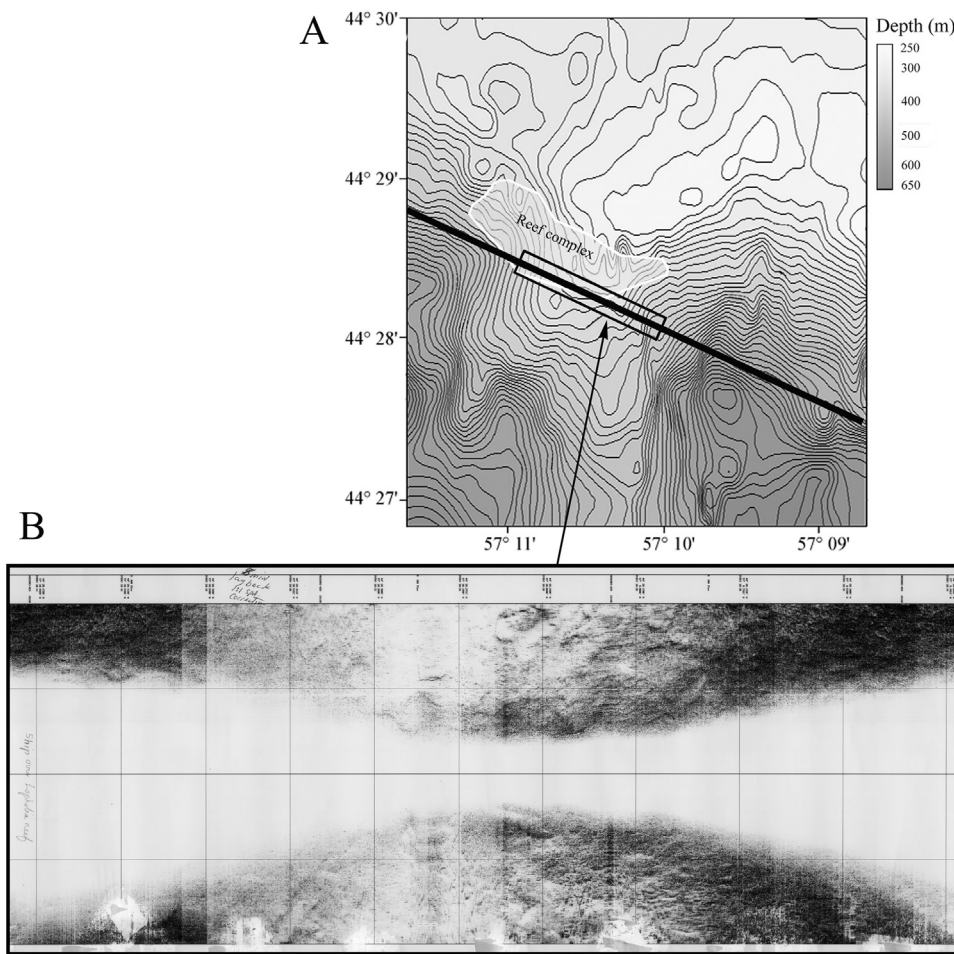|	Sand		Pebble		Cobble		Boulder	
	Without	With	Without	With	Without	With	Without	*With*
Mean % cover	64.7	40.2	16.2	23.8	14.5	21.6	4.8	14.4
Variance	488.7	80.7	107.4	22.5	79.6	47.7	17.5	57.5
t Stat	4.99241		−3.20275		−2.71250		−4.15289	
P(T ≤ t) two-tail	0.00001		0.00275		0.01148		0.00098	

Fig. 5. Location of sidescan sonar survey line over the study area (A). The sonar image (B) indicates a rugged seafloor with variable backscatter strength, partly overlapping with the occurrence of the reef complex (A).

the Atlantic North American coast, well developed reefs only occur south of Cape Lookout, NC. Brooke and Ross (2014) discuss this and conclude that lack of suitable habitat and exposure to high turbidity are likely explanations. The isolated live colonies commonly occur on vertical cliffs, often under overhangs where they may get protection against sinking particles. North of Atlantic Canada, the closest *L. pertusa* occurrences are located on the margins south of Iceland and east of southern Greenland (Buhl-Mortensen et al., 2015; Kenchington et al., 2016). In this context, the Stone Fence is unique, being the only documented *Lophelia*-reef along a distance of > 4000 km.

The hydrographic conditions, influenced by four main water masses (the Labrador Current, the Labrador Slope Water, The Labrador Sea Water and the Gulf Stream) are probably the major controlling factors of the distribution of corals in Atlantic Canada. Mortensen and Buhl-Mortensen (2004) suggest that incursion of warm water from the Gulf Stream limits the upper depth range of *P. arborea* and *P. resedaeformis*. The variation in temperature is great on the shallow (mainly < 200 m) Scotian Slope. The larger shelf incisions (e.g. Gulf of Maine, The Gully, and The Laurentian Channel) may serve as a "buffer" of the variable temperatures occurring in open slope areas of the Atlantic Canadian continental margin.

5.2. Impact of demersal fishing

Reefs of *L. pertusa* and of other cold-water scleractinians have been shown to be very sensitive to fishing activities and steps have been taken to protect them (Koslow et al., 2001; Fosså et al., 2002). Georeferenced fishery observer records show that the mouth of the Laurentian Channel, including the Stone Fence, has been a popular fishing area for many years and was subjected to heavy trawling almost every

year between 1980 and 2000 (Fig. 6). Our video observations clearly indicate that the reef complex has been damaged by fishing activity. Colonies were fractured and tilted, boulders were overturned and direct signs of fishing activity were evident. The large proportion of area with rubble indicates that a larger and healthier reef complex was previously present at this site. Substantial fishing effort for both redfish and halibut over the reef complex is also evident in the 1998–2003 observer and DFO landings databases. Although coral rubble is commonly a common substrate type on un-disturbed reefs (Mortensen et al., 1995), rubble is more dominating on reefs impacted by bottom trawling (Fosså et al., 2002). It can however be difficult to distinguish naturally occurring rubble, caused by natural ageing processes, with rubble created by bottom trawling.

The observed mass occurrences of zoanthid anemones may represent an opportunistic recruitment after habitat destruction. These organisms may cause further mortality to damaged corals. Similar zoanthid colonization on broken parts of live coral colonies has been seen commonly elsewhere. In the Northeast Channel, southwest of Nova Scotia, Mortensen and Buhl-Mortensen (2004) observed zoanthids colonizing broken colonies of *P. resedaeformis*. Carlgren (1945) describes the presence of sclerites from the host inside the tissue of parasitic zoanthid *Epizoanthus norvegicus*.

A recent review of VMS and logbook data collected after the closure was established indicates that the closure is generally respected by trawlers (T. Koropatnick, DFO, Bedford Institute of Oceanography, personal communication). The pattern is not so clear for bottom long-line vessels, as VMS and observer data provide evidence for occasional incursions into the closure area. While some of these incursions may be intentional, gear drift due to high currents in the area may also be a factor. Regardless of the intent, the reef remains at risk as long as

Table 3
Densities of other corals observed along the video transects (2002 and 2003) (individuals or colonies per 100 m^2 depending on taxon).

Transect	Acanthogorgia	Anthomastus	Duva	Flabellum	Keratoisis	Paragorgia	Primnoa
25-02	4.75	0.00	0.00	0.00	0.00	0.00	0.00
26-02	3.79	0.03	0.08	0.03	0.00	0.00	0.00
27-02	3.12	0.35	0.02	0.02	0.00	0.00	0.00
28-02	2.21	0.25	0.40	0.16	0.00	0.00	0.00
29-02	3.48	0.84	0.99	0.76	0.00	0.00	0.00
29a-02	1.39	1.46	0.98	0.34	0.00	0.00	0.00
29b-02	0.69	0.36	0.44	0.22	0.09	0.00	0.02
31-02	0.88	0.97	0.57	0.35	0.00	0.00	0.00
32-02	1.73	0.55	0.26	0.03	0.00	0.00	0.00
33-02	2.08	0.32	0.36	0.14	0.00	0.00	0.00
34-02	2.66	0.11	0.16	0.10	0.00	0.00	0.00
35-02	3.80	0.04	0.06	0.03	0.00	0.00	0.00
36-02	3.82	0.02	0.06	0.01	0.00	0.00	0.00
37-02	4.30	0.06	0.07	0.01	0.00	0.00	0.00
60-02	4.80	0.77	0.86	0.23	0.00	0.00	0.00
70-02	0.26	0.04	0.00	0.00	0.02	0.00	0.00
21-03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-03	3.38	3.06	0.13	0.00	0.00	0.00	0.00
24-03	0.06	0.00	3.55	0.00	0.00	0.00	1.74
25-03	0.51	0.06	0.00	0.00	0.11	0.11	0.00
26-03	0.19	0.46	1.51	0.00	0.03	0.09	0.17
27-03	1.25	0.20	0.08	0.00	0.08	0.03	0.03
28-03	0.09	0.33	0.70	0.00	0.05	0.05	0.00
29-03	0.09	0.37	13.80	0.00	0.19	0.56	0.83
30-03	1.17	0.22	3.06	0.06	0.22	0.06	0.00
31-03	0.80	0.04	3.57	0.00	0.00	0.00	0.00
32-03	0.95	5.40	0.90	0.00	0.00	0.00	0.00
33-03	0.00	0.19	7.05	0.00	0.00	0.00	0.00
34-03	0.23	0.06	5.87	0.00	0.00	0.00	0.29
35-03	0.00	0.00	2.29	0.00	0.00	0.00	0.00
36-03	0.36	0.36	0.00	0.00	0.00	0.00	0.00
37-03	0.11	13.60	2.39	0.00	0.11	0.22	0.00
38-03	0.03	0.39	1.59	0.00	0.00	0.68	3.31
39-03	0.00	0.00	5.28	0.00	0.00	0.70	1.38
40-03	0.05	0.09	9.60	0.00	0.00	0.05	0.09
41-03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42-03	0.00	0.28	0.00	0.00	0.00	0.33	0.89
43-03	0.12	0.12	13.90	0.00	0.00	0.83	0.47
44-03	0.00	0.00	0.00	0.00	0.00	0.16	0.74
45-03	0.00	0.00	9.20	0.00	0.00	1.20	1.70
With *Lophelia*	0.14	0.15	3.76	0.02	0.02	0.35	0.88
Without *Lophelia*	1.84	1.06	1.60	0.08	0.02	0.03	0.04

bottom-contacting gear has the potential to encroach on the reef. DFO managers are continuing discussions with industry to address this risk (Derek Fenton, DFO, pers. comm).

Despite the obvious damage, there are signs that recovery is possible. Most of the observed colonies of both *L. pertusa* and *P. arborea* are small. Applying reported growth rates of 2 cm per year for *L. pertusa* (Gass and Roberts, 2006, Mortensen and Lepland, 2007) and 4 cm per year for small (< 80 cm tall) *P. arborea* (Mortensen and Buhl-Mortensen, 2005b; Bennecke et al., 2016), colonies of *L. pertusa,* 15 cm tall and *P. arborea,* 30 cm tall would be on the order of 8 years old. This indicates that at least some sites within the study area have a potential for recovery during a period of heavy fishing activity. *Lophelia* reefs are old structures and the relevant time scale to assess the effect of chronic disturbance is over decades rather than years.

5.3. Conservation of the reef complex

It was recognized that the discovery of this *L. pertusa* reef complex was a noteworthy event and extensive media coverage ensued. Both DFO and the fishing industry recognized that immediate steps must be taken to protect the reef complex from further damage. Environmental organizations also expressed their concerns over the need to protect this ecologically valuable and sensitive coral habitat. Major considerations were how large an area should be protected, what closure mechanism should be used and what the impact on current fisheries would be. A

working group of DFO and fishing industry personnel reviewed the available scientific information and debated different proposals (Breeze and Fenton, 2007). In the end, it was decided to close an area of approximately 15 km^2 centred over the reef complex (Fig. 6). The closure was by variation order (within the Fisheries Act) dated 7 June 2004 and remains in force through license conditions until otherwise revoked (Department of Fisheries and Oceans, 2004). All bottom contacting fishing gear (i.e. trawls, longlines, pots, etc.) is excluded but pelagic fisheries can still take place. This closure should protect the observed reef complex from further damage from fishing gear and allow recovery, which could take a century or more. The effectiveness of the closure should be reviewed on a regular basis.

The Stone Fence *Lophelia* conservation area was the third closure established in Atlantic Canada to protect cold-water corals. In 2002, DFO established a 424 km^2 coral conservation area in the Northeast Channel which contains a high density of colonies of the gorgonians *P. arborea* and *P. resedaeformis* (Mortensen and Buhl-Mortensen, 2004). The entire area is closed to trawling while 10% is open to longline fishing with an observer onboard. In 2004, The Gully, a submarine canyon off Nova Scotia, was declared a marine protected area (MPA) under the Canada Oceans Act. The Gully supports a wide diversity of cold-water corals and associated species (Mortensen and Buhl-Mortensen, 2005a). The Gully MPA comprises 2364 km^2 in area. All fisheries are excluded from deep-water areas (> 600 m) while limited fisheries (longline for halibut and large pelagics) are allowed in
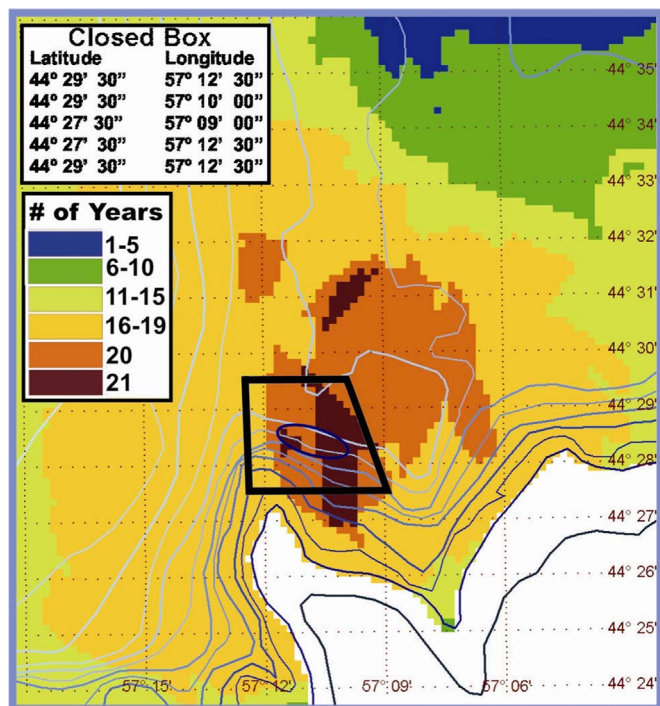
Fig. 6. Spatial distribution of otter trawling disturbance as estimated from Fishery Observer Program data (1980–2000). The different colours indicate the number of years (out of 21) that more than 50% of the seabed was potentially disturbed. The ellipse indicates the approximate position of the reef complex while the heavy black lines mark the boundaries of the coral protection area created in 2004 which is closed to all bottom-contacting fishing activity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

shallower waters. As well as protecting coral and associated species from fishing activities, these three conservation areas provide scientists the opportunity to study cold-water corals in relatively undisturbed habitats.

5.4. Further studies

It is likely that other similar *L. pertusa* reef structures exist in Atlantic Canada. Just a very small part of the potential habitat of *L. pertusa* in Atlantic Canada has been examined by video. The limited sidescan sonar data collected in our study area by the Geological Survey of Canada indicate the possible occurrence of additional reefs in the vicinity of the reef structure we have documented. Analysis of video suggests that *L. pertusa* may have been present at some time along a transect surveyed in 2002 further inside the Laurentian Channel along the edge of Banquereau. Bycatch records also indicate the presence of *L. pertusa* in the Gully and Jordan Basin.

Because of their ecological importance and susceptibility to damage by human activities, it is important that these additional reef structures be located and documented. In 2009, DFO revisited the reef area with CCGS *Hudson* and conducted some surveys using a platform with video and still cameras. Only a few occurrences of live *Lophelia* were documented so the status of the reef complex could not be assessed (Cogswell et al., 2009). The reef needs to be mapped in more detail and additional targeted video surveys should be performed to provide a baseline for monitoring. This can best be done using an ROV in a systematic way targeting the areas where live corals were spotted in this study and a more complete survey of the areas in between the mounds. Without a multibeam map of the detailed bathymetry to serve as a planning tool, the visual exploration of the area is challenging. Even with heights less than 3 m, the reef structures we observed should be detectable in multibeam data with 5 m horizontal resolution (Roberts et al., 2005). High priority should be given to conducting such surveys

in the Laurentian Channel which is of future interest to the oil and gas industry and continues to be important for several bottom fisheries (Breeze and Horsman, 2005).

References

Baker, K.D., Wareham, V., Snelgrove, P.V.R., Haedrich, R.L., Fifield, D.A., Edinger, E.N., Gilkinson, K.D., 2012. Distributional patterns of deep-sea coral assemblages in three submarine canyons off Newfoundland, Canada. Mar. Ecol. Prog. Ser. 445, 235–249.

Bennecke, S., Kwasnitschka, T., Metaxas, A., Dullo, W.C., 2016. In situ growth rates of deep-water octocorals determined from 3D photogrammetric reconstructions. Coral Reefs 35, 1227–1239. http://dx.doi.org/10.1007/s00338-016-1471-7.

Bennecke, S., Metaxas, A., 2017. Effectiveness of a deep-water coral conservation area: evaluation of its boundaries and changes in octocoral communities over 13 years. Deep-Sea Res. II 137, 420–435.

Breeze H., Davis, D.S., Butler, M., Kostylev, V., 1997. Distribution and status of deep sea corals off Nova Scotia. Ecology Action Centre, Marine Issues Committee Special Publication Number 1, 58 p.

Breeze, H., Horsman, T., 2005. The Scotian Shelf: An Atlas of Human Activities. Oceans and Coastal Management Division Oceans and Habitat Branch Fisheries and Oceans Canada (Maritimes Region), ISBN 0-662-69160-1, 113 p.

Breeze, H., Fenton, D.G., 2007. Designing management measures to protect cold-water corals off Nova Scotia, Canada. In: George, R.Y., Cairns, S.D. (Eds.), Conservation and Adaptive Management Of Seamount And Deep-sea Coral Ecosystems. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, pp. 123–133 (324 p).

Brooke, S., Järnegren, J., 2013. Reproductive periodicity of the scleractinian coral Lophelia pertusa from the Trondheim Fjord, Norway. Mar. Biol. 160, 139–153.

Brooke, S., Ross, S.W., 2014. First observations of the cold-water coral *Lophelia pertusa* in mid-Atlantic canyons of the USA. Deep-Sea Res. Pt II 104, 245–251.

Buhl-Mortensen, L., Olafsdottir, S.H., Buhl-Mortensen, P., Burgos, J.M., Ragnarsson, S.A., 2015. Distribution of nine cold-water coral species (Scleractinia and Gorgonacea) in the cold temperate North Atlantic in light of bathymetry and hydrography. Hydrobiologia 759, 39–61.

Buhl-Mortensen, L., Vanreusel, A., Gooday, A.J., Levin, L.A., Priede, I.G., Buhl-Mortensen, P., Gheerardyn, H., King, N.J., Raes, M., 2010. Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Mar. Ecol. 31, 21–50.

Carlgren, O., 1945. Polyppdyr (Coelenterata) III. Koraldyr. Danmarks fauna 51. G. E. C. Gads forlag, København. 168 p.

Cogswell, A.T., Kenchington, E.L.R., Lirette, C.G., MacIsaac, K., Best, M.M., Beazley, L.I., Vickers, J., 2009. The current state of knowledge concerning the distribution of coral in the Maritime provinces. Can. Tech. Report. Fish. Aquat. Sci. 2855, 66.

Collins, J.W., 1884. On the occurrence of corals on the Grand banks. Bull. U. S. Fish. Commision 1884, 237–248.

Costello, M.J., McCrea, M., Freiwald, A., Lundalv, T., Jonsson, L., Bett, B.J., van Weering, T.C.E., de Hass, H., Roberts, M.J., Allen, D., 2005. Role of cold-water *Lophelia pertusa* coral reefs as fish habitat in the NE Atlantic. In: Freiwald, A., Roberts, J.M. (Eds.), Cold-Water Corals and Ecosystems. Springer, Berlin, Germany, pp. 771–805.

Davies, A.J., Guinotte, J.M., 2011. Global habitat suitability for framework-forming cold-water corals. PLoS One 6, e18483. http://dx.doi.org/10.1371/journal.pone.0018483.

Deichmann, E., 1936. The Alcyonaria of the Western Part of the Atlantic Ocean 53. Harvard University, Museum of Comparative Zoology, Cambridge, USA, Memoirspp. 1–317.

Department of Fisheries and Oceans, 2004. Press release (⟨http://www.mar.dfo-mpo.gc.ca/communications/maritimes/news04e/NR-MAR-040-14E.html⟩).

Dodds, L.A., Roberts, J.M., Taylor, A.C., Marubini, F., 2007. Metabolic tolerance of the

cold-water coral Lophelia pertusa (Scleractinia) to temperature and dissolved oxygen change. J. Exp. Mar. Biol. Ecol. 349, 205–214.

Dullo, W., Chr, Flögel, S., Rüggeberg, A., 2008. Cold-water coral growth in relation to the hydrography of the Celtic and Nordic European continental margin. Mar. Ecol. Progress. Ser. 371, 165–175.

Edinger, E.N., Sherwood, O.A., Piper, D.J., Wareham, V.E., Baker, K.D., Gilkinson, K.D., Scott, D.B., 2011. Geological features supporting deep-sea coral habitat in Atlantic Canada. Cont. Shelf Res. 31, 69–84.

Fader, G.B., King, L.H., Josenhans, H.W., 1982. Surficial geology of the Laurentian Channel and the western Grand Banks of Newfoundland. Geological Survey of Canada, Paper no. 81-22, 37 p.

Fisheries Resource Conservation Council, 2002. Conservation requirements for ground-fish stocks on the Scotian Shelf and in the Bay of Fundy (4VWX), in Sub-Areas 0, 2 + 3 and redfish stocks. Report to the Minister of Fisheries and Oceans. FRCC.2002.R.1, January 2002, 116 p.

Fosså, J.H., Mortensen, P.B., Furevik, D.M., 2002. The cold-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. Hydrobiologia 471, 1–12.

Frederiksen, R., Jensen, A., Westerberg, H., 1992. The distribution of the scleractinian coral *Lophelia pertusa* around the Faroe Islands and the relation to internal mixing. Sarsia 77, 157–171.

Freiwald, A., Wilson, J.B., Henrich, R., 1999. Grounding Pleistocene icebergs shape recent cold-water coral reefs. Sed. Geol. 125, 1–8.

Gass, S.E., Willison, J.H.M., 2005. An assessment of the distribution and status of deep sea corals in Atlantic Canada by using both scientific and local forms of knowledge. In: Proceedings of the 2nd International Symposium on Deep Sea corals. Sept. 2003, Erlangen, Germany.

Gass, S.E., Roberts, J.M., 2006. The occurrence of the cold-water coral *Lophelia pertusa* (Scleractinia) on oil and gas platforms in the North Sea: colony growth, recruitment and environmental controls on distribution. Mar. Poll. Bull. 52, 549–559.

Gordon, D.C., Kenchington, E.L.R., Gilkinson, K.D., McKeown, D.L., Steeves, G., Chin-Yee, M., Vass, W.P., Bentham K., Boudreau, P.R., 2000. Canadian imaging and sampling technology for studying marine benthic habitat and biological communities. ICES Ann. Sci. Conf. CM 2000/T:07.

Han, G., Loder, J.W., Smith, P.C., 1998. Seasonal-mean hydrography and circulation in the Gulf of St. Lawrence and on the eastern Scotian and southern Newfoundland shelves. J. Phys. Oceanogr. 29, 1279–1301.

Henry, L.-A., Roberts, J.M., 2007. Biodiversity and ecological composition of macro-benthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. Deep-Sea Res. I. 54, 654–672.

Husebø, A., Nøttestad, L., Fosså, J.H., Furevik, D., Jørgensen, S., 2002. Distribution and abundance of fish in deep-sea coral habitats. Hydrobiologia 471, 91–99.

Jensen, A., Frederiksen, R., 1992. The fauna associated with the bank-forming cold-water coral *Lophelia pertusa* (Scleractinaria) on the Faroe shelf. Sarsia 77, 53–69.

Kenchington, E., Yashayaev, I., Tendal, O.S., Jørgensbye, H., 2016. Water mass characteristics and associated fauna of a recently discovered *Lophelia pertusa* (Scleractinia: anthozoa) reef in Greenlandic waters. Polar Biol. http://dx.doi.org/10.1007/s00300-016-1957-3.

Koslow, J.A., Gowlett-Holmes, K., Lowry, J.K., O'Hara, T., Poore, G.C.B., Williams, A., 2001. Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. Mar. Ecol. Prog. Ser. 213, 111–125.

Krieger, K.J., 2001. Coral (*Primnoa*) impacted by fishing gear in the Gulf of Alaska. In: Willison, J.H.M., Hall, J., Gass, S.E., Kenchington, E.L.R., Butler M., Doherty P., (Eds.) Proceedings of the First International Symposium on Deep-Sea Corals, pp. 106–116.

Kulka, D.W., Pitcher, D.A., 2001. Spatial and temporal patterns in trawling activity in the Canadian Atlantic and Pacific. ICES CM 2001/R:02.

Larsson, A.I., Järnegren, J., Strömberg, S.S., Dahl, M.P., Lundälv, T., Brooke, S., 2014. Embryogenesis and larval biology of the cold-water coral *Lophelia pertusa*. PLoS ONE 9 (7), e102222.

Lauzier, L.M., Trites, R.W., 1958. The deep waters of the Laurentian Channel. J. Fish. Res. Board Can. 15, 1247–1257.

López Correa, M., Montagna, P., Joseph, N., Rüggeberg, A., Fietzke, J., Flögel, S., Dorschel, B., Goldstein, S.L., Wheeler, A., Freiwald, A., 2012. Preboreal onset of Norwegian cold-water coral growth beyond the Arctic Circle revealed by radiocarbon and U-series dating and neodymium isotopes. Quat. Sci. Rev. 34, 24–43. http://dx.doi.org/10.1016/j.quascirev.2011.12.005.

MacIsaac, K., Bourbonnais, C., Kenchington, E., Gordon Jr. D.C., Gass, S., 2001. Observations on the occurrence and habitat preference of corals in Atlantic Canada. In: Willison, J.H.M., Hall, J., Gass, S.E., Kenchington, E.R.L., Butler, M., Doherty P., (Eds.) Proceedings of the First International Symposium on Deep-Sea Corals, pp. 58–75.

Mohn, C., Rengstorf, A., White, M., Duineveld, G., Mienis, F., Soetaert, K., Grehan, A., 2014. Linking benthic hydrodynamics and cold-water coral occurrences: a high-resolution model study at three cold-water coral provinces in the NE Atlantic. Prog. Oceanogr. 122, 92–104.

Mortensen, P.B., 2000. *Lophelia pertusa* (Scleractinia) in Norwegian waters. Distribution, Growth, And Associated Fauna (Dr. scient. thesis). Department of Fisheries and Marine Biology, University of Bergen, Norway.

Mortensen, P.B., Buhl-Mortensen, L., 2004. Distribution of cold-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). Mar. Biol. 144, 1223–1238.

Mortensen, P.B., Buhl-Mortensen, L., 2005a. Coral habitats in The Gully, a submarine canyon off Atlantic Canada. In: Freiwald, A., Roberts, J.M. (Eds.), Cold-water Corals and Ecosystems. Springer-Verlag, Berlin Heidelberg, pp. 247–277.

Mortensen, P.B., Buhl-Mortensen, L., 2005b. Morphology and growth of the deep-water gorgonians *Primnoa resedaeformis* and *Paragorgia arborea*. Mar. Biol. 147, 775–788.

Mortensen, P.B., Fosså, J.H., 2006. Species diversity and spatial distribution of in-vertebrates on *Lophelia* reefs in Norway. In: Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan, pp. 1849–1868.

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

Mortensen, P.B., Hovland, M.T., Fosså, J.H., Furevik, D.M., 2001. Distribution, abundance and size of *Lophelia pertusa* coral reefs in mid-Norway in relation to seabed characteristics. J. Mar. Biol. Ass. UK 81, 81–597.

Mortensen, P.B., Buhl- Mortensen, L., Gordon Jr, D.C., Fader, G.B.J., McKeown, D.L., Fenton, D.G., 2005. Effects of fisheries on deep-water gorgonian corals in the Northeast channel, Nova Scotia (Canada). Am. Fish. Soc. Symp. 41, 369–382.

Mortensen, P.B., Buhl-Mortensen, L., Gordon Jr D.C., 2006. Distribution of deep-water corals in Atlantic Canada. In: Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan, pp 1832–1848.

Mortensen, P.B., Lepland, A., 2007. Ecological consequences of exploration drilling on coral reefs in the Træna Deep. Fisken og havet No 7-2007, 87p.

Mortensen, P.B., Rapp, H.T., 1998. Oxygen and carbon isotope ratios related to growth line patterns in skeletons of *Lophelia pertusa* (L) (Anthozoa: scleractinia): implications for determination of linear extension rates. Sarsia 83, 433–446.

Mosher, D.C., Piper, D.J.W., 2007. Multibeam Seafloor Imagery of the Laurentian Fan and the 1929 Grand Banks Landslide Area. Geological Survey of Canada, Darmouth, Nova Scotia (Open File 5638).

Roberts, J.M., Brown, C.J., Long, D., Bates, C.R., 2005. Acoustic mapping using a mul-tibeam echosounder reveals coldwater coral reefs and surrounding habitats. Coral Reefs 24, 654–669.

Roy, S., Silverberg, N., Romero, N., Deibel, D., Klein, B., Savenkoff, C., Vézina, A., Tremblay, J.E., Legendre, L., Rivkin, R.B., 2000. Importance of mesozooplankton feeding for the downward flux of biogenic carbon in the Gulf of St. Lawrence (Canada). Deep-Sea Res. Pt. II 47, 519–544.

Strømgren, T., 1971. Vertical and horizontal distribution of *Lophelia pertusa* (Linne) in Trondheimsfjorden on the west coast of Norway. Det. K. Nor. Vidensk. Selsk. Skr. 6, 1–9.

Verrill, A.E., 1922. The Alcyonaria of the Canadian Arctic Expedition, 1913–1918, with a revision of some other Canadian genera and species. Report of the Canadian Arctic Expedition 1913–1918, Vol VIII: Molluscs, Echinoderms, Coelenterates, Etc. Part G: Alcyonaria and Actinaria.

Watanabe, S., Metaxas, A., Sameoto, J., Lawton, P., 2009. Patterns in abundance and size of two deep-water gorgonian octocorals, in relation to depth and substrate features off Nova Scotia. Deep Sea Research Part I 56. pp. 2235–2248.

Wareham, V.E., Edinger, E.N., 2007. Distribution of deep-sea corals in the Newfoundland and Labrador region, Northwest Atlantic Ocean. In: George, R.Y., Cairns, S.D. (Eds.), Conservation and Adaptive Management of Seamount and Deep-sea Coral Ecosystems. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, pp. 289–313.

Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. J. Geol. 30, 377–392.

Wheeler, A.J., Beyer, A., Freiwald, A., de Haas, H., Huvenne, V.A.I., Kozachenko, M., Olu-Le Roy, K., Opderbecke, J., 2007. Morphology and environment of cold-water coral carbonate mounds on the NW European margin. Int. J. Earth Sci. 96, 37–56. http://dx.doi.org/10.1007/s00531-006-0130-6.

Zibrowius, H.W., 1980. Les scléractiniaires de la Méditerranée et de l'Atlantique nord-oriental. Mémoires de l'Institut océanographique, no 11. Monaco Institut océanographic. Description 3 v. (284 p., 107 p. of plates).