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Effectiveness of a deep-sea cold-water coral Marine Protected Area, following eight years of fisheries closure

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ABSTRACT

Pressure on deep-sea ecosystems continues to increase as anthropogenic activities move into ever deeper waters. To mitigate impacts on vulnerable habitats, various conservation measures exist, such as the designation of Marine Protected Areas (MPAs). So far, however, little evidence is available about their effectiveness. This paper presents a unique follow-up study assessing the status and recovery of a deep-sea fisheries closure and MPA at ~1000 m water depth in the NE Atlantic, eight years after designation. The Darwin Mounds cold-water coral ecosystem was discovered in 1998, and closed to all bottom contact fisheries, especially trawling, in 2003. Our repeat survey in 2011 used both high-resolution sidescan sonar data collected by Autonomous Underwater Vehicle (AUV) and video footage from a Remotely Operated Vehicle (ROV) to evaluate recovery. The results demonstrate that (1) protection was successful and fishing impact was largely avoided in the Western Darwin Mounds, which contained similar proportions of live cold-water coral occurrence in 2011 as observed in 1998–2000; however (2) the Eastern Darwin Mounds suffered severe damage pre-closure, and by 2011 showed no coral recolonisation and very little regrowth. These results are further evidence for the low resilience and slow recovery potential of deep-sea ecosystems, and underline once again the importance of the precautionary principle in deep-sea conservation.

1. Introduction

1.1. Context: cold-water corals, bottom trawling and the effectiveness of conservation measures

Over the last decade, increasing evidence of the environmental impacts of deep-water demersal fisheries, especially bottom trawling (e.g. Benn et al., 2010; Puig et al., 2012; Pusceddu et al., 2014), has resulted in the development of several national and international policies to protect deep-sea vulnerable marine ecosystems (VMEs). The process is largely driven by international agreements and directives, such as the United Nations General Assembly resolutions 61/105 and 64/72 on sustainable fisheries (UNGA, 2006, 2009), or the EC Habitats Directive, which as a result of the so-called 'Greenpeace judgement' was explicitly deemed applicable not only to coastal waters, but also to Member States' 200 nm Exclusive Economic Zones (De Santo, 2013). To implement the conservation policies, increasing numbers of fisheries closures, deep-water Marine Protected Areas (MPAs), MPA networks, and Special Areas of Conservation (SACs) are being designated, also in offshore waters. So far, however, limited evidence exists about their effectiveness, especially on the longer term. It remains a question how well deep-sea ecosystems recover, and to what extent conservation strategies for shallow-water settings need to be adapted for deep-water application.

Cold-water corals, the azooxanthellate species of scleractinian, antipatharian, gorgonian and stylasterid coral that are not restricted to the photic zone, are important habitat-forming organisms in the deep sea (e.g. Rogers, 1999; Roberts et al., 2009). They are among the VMEs that require protection (UNGA, 2006; FAO, 2009), while reef habitats, including deep-water reefs, are protected under Annex I of the EC Habitats Directive. They create habitat complexity in otherwise (apparently) homogeneous, sedimented environments, resulting in an increased biodiversity (Henry and Roberts, 2007; Bongiorni et al., 2010). In addition, cold-water coral reefs may act as nursery grounds and adult habitat for commercial fish species (e.g. Costello et al., 2005; Söffker et al., 2011; Baillon et al., 2012).

However, deep-water bottom trawling is particularly destructive for cold-water coral reefs, which are relatively fragile and slow-growing (Hall-Spencer et al., 2002). The technique has been compared to forest clear-cutting (Watling and Norse, 1998), and the effects on cold-water corals have been reported from several locations (e.g. coral gardens along the Aleutian Islands (Shester and Ayers, 2005; Heifetz et al., 2009); *Oculina* reefs offshore Florida (Reed et al., 2007); stony coral habitat on seamounts offshore New Zealand and Australia (Williams et al., 2010)). Fosså et al. (2002) estimated that between 30 and 50% of *Lophelia* reefs offshore Norway were impacted by bottom trawling.

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In addition to the physical damage, the indirect effects include biodiversity loss, community changes (Althaus et al., 2009) and coral smothering by resuspended sediment (Larsson and Purser, 2011).

In several cases, these observations have triggered conservation measures, often based on temporary or permanent area closures. The restrictions may apply to either bottom trawling only, or to all bottom contact gear. Although in general these closures seem fairly well respected (e.g. Armstrong and van den Hove, 2008), and in some cases are even developed by the fishing industry itself (e.g. Benthic Protection Areas offshore New Zealand; Helson et al. (2010)), so far there is little information about recovery rates of the coral ecosystems. In the few cases where follow-up surveys have been carried out, trawling impacts seem to persist for over a decade, and recovery is slow (e.g. in the *Oculina* reefs offshore Florida, protected for 15 years (Reed et al., 2007); in the *Solenosmilia* reefs offshore Australia and New Zealand, protected for 5–10 years (Althaus et al., 2009; Williams et al., 2010); or based on modelling studies for a wide range of sponge and coral species around the Aleutian Islands, Alaska (Rooper et al., 2011)). In order to support further policy development and the continued sustainable management of the deep ocean, there is an urgent need for more information on the effectiveness of conservation measures in the deep sea, and the recovery rates of deep-sea habitats. So far no long-term studies (~10 years) have been published from the NE Atlantic, where *Lophelia pertusa* and *Madrepora oculata* are the main reef framework building species. This paper describes the situation in the Darwin Mounds, an area of small cold-water coral mounds protected from bottom trawling since 2003. A repeat survey in 2011 provided the unique opportunity to evaluate the status of the cold-water coral habitat after eight years of protection, and gave insight in the recovery potential of a deep-water VME.

1.2. Darwin Mounds

The Darwin Mounds are a field of small cold-water coral mounds, each up to 75 m across and 5 m high, found at about 1000 m water depth in the northern Rockall Trough, west of Scotland (Fig. 1). They were discovered in 1998 (Masson and Jacobs, 1999; Bett, 2001). Subsequent ground-truthing with high-resolution sidescan sonar and video confirmed the mounds were covered with cold-water corals, while recently recovered piston cores demonstrated that a dense framework of fossil coral fragments could also be found within the mounds (Victorero et al., 2015). The main framework-forming species are *Lophelia pertusa* L. and *Madrepora oculata* L. (Masson et al., 2003), occurring together with, among others, soft corals, sponges, tube-forming polychaetes, squat lobsters and echiuran worms (Kiriakoulakis et al., 2004; Howell et al., 2014). In the surrounding areas, and especially in the scoured 'tail' features (Masson et al., 2003), high numbers of the giant single-celled organism *Syringammina fragilissima* have been reported (Xenophyophores: Gooday and Tendal, 2000; Hughes and Gooday, 2004).

The high-resolution sidescan sonar and video data also illustrated heavy impacts from bottom trawling (Wheeler et al., 2005). These observations, together with the fact that at the time of discovery, the Darwin Mounds were the only example of *Lophelia* growing on sandy rather than rocky substrata, were the main drivers behind the development of a conservation policy. This started with an emergency closure under the EU Common Fisheries Policy (CFP) in August 2003, that was made permanent in March 2004 (De Santo and Jones, 2007). The Darwin Mounds became the first offshore MPA for the UK (De Santo, 2013), and were also designated as Special Area of Conservation under the EC Habitats Directive in December 2015 (JNCC, 2015). The implementation of these protection measures is being managed by the UK's Joint Nature Conservation Committee (JNCC) and Marine Scotland.

Since the initial discovery and surveys in 1998–2000, no further scientific surveys had been carried out in this area until May 2011, and the status of the mound province and the effect of the protection measures were unknown. A study by Davies et al. (2007) based on Vessel Monitoring System (VMS) data indicated an increase in vessel activity in the area just before the closure was put in place. This could have been

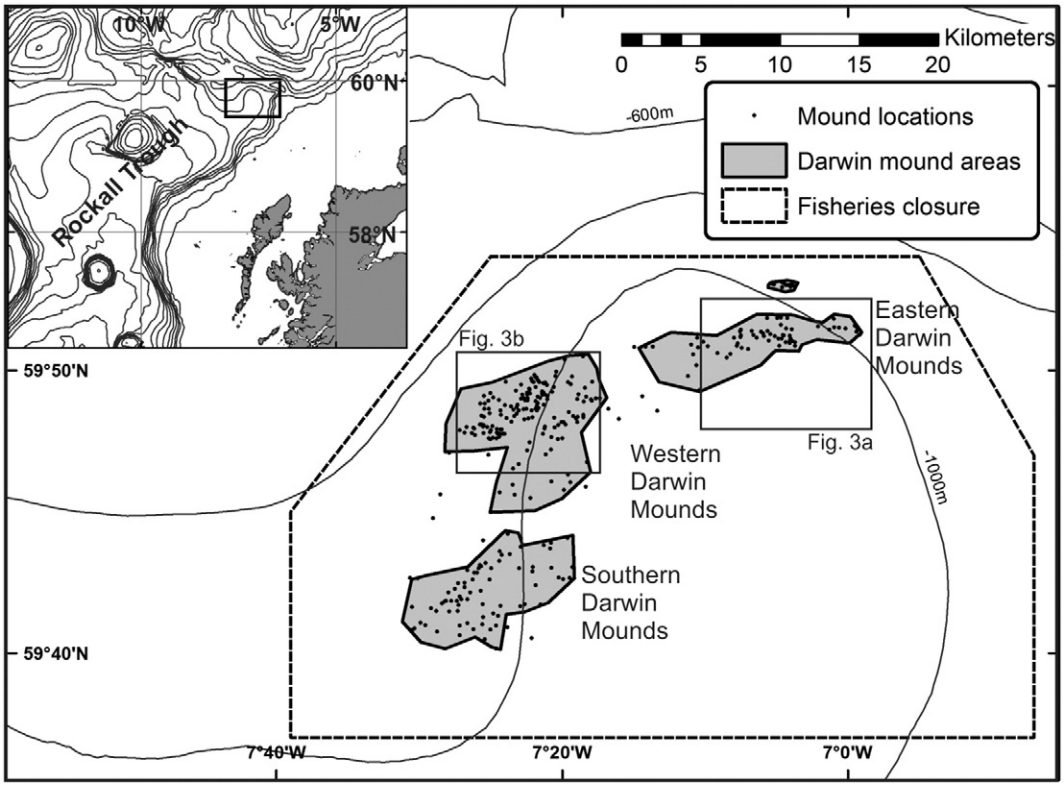

Fig. 1. Location map of the Darwin Mound fisheries closure and Marine Protected Area in the Northern Rockall Trough. Locations of all Darwin Mounds in the area (solid dots) were digitised from ancillary sidescan sonar data (after Huvenne et al., 2009a). Grey boxes outline the locations of Fig. 3.