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Effectiveness of a deep-water coral conservation area: Evaluation of its boundaries and changes in octocoral communities over 13 years

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ABSTRACT

Over the past 15 years, multiple areas in the North Atlantic have been closed to destructive fishing practices to protect vulnerable deep-water coral ecosystems, known to provide habitat for diverse associated fauna. Despite the growing number of conservation measures, long-term studies on the recovery of deep-water coral communities from fisheries impacts remain scarce. In the Gulf of Maine, the Northeast Channel Coral Conservation Area (NECCCA)[1] was established in 2002 to protect dense aggregations of the two numerically dominant octocoral species in the region, *Primnoa resedaeformis* and *Paragorgia arborea*. To evaluate the effectiveness of the conservation measures, we monitored shifts in abundance and size of these two coral species in the shallow section (400–700 m) of the NECCCA for 12 years after the fisheries closure. We also evaluated the appropriateness of the location of the deep boundaries of the NECCCA that were placed based on a precautionary approach with limited information on coral distribution at depths > 500 m. Video transects were conducted with ROV "ROPOS" in 2001, 2006, 2010 and 2014. We found potential signs of recovery from fisheries impact at some of the shallow locations in 2014: higher coral abundance and the presence of some very large colonies as well as recruits compared to 2001 and 2006. However, spatial heterogeneity was pronounced and small colonies (< 20 cm) indicative of successful recruitment were not found at all sites, underscoring the need for long-term protection measures to allow full recovery of impacted coral communities. At 700–1500 m different coral taxa were dominant than at the shallow locations and coral abundance peaked between 700 and1200 m. High abundance and diversity of corals at this depth range, 8–10 km southwest of the NECCCA, suggest that an extension of the southwest boundary should be considered. Comparably low coral abundance was found at depths of 1200–1500 m inside the NECCCA indicating an appropriate initial placement of the southeast boundary. These are the first long-term observations of protected deep-water octocoral communities which are needed for the effective management of deep-water coral conservation areas.

1. Introduction

Deep-water corals enhance the structural complexity of the seafloor and provide habitat for a diverse associated fauna (Roberts et al., 2006). Fish and invertebrates, such as echinoderms and crustaceans, are found on and among the colonies for protection, feeding and attachment (De Clippele et al., 2015; Du Preez and Tunnicliffe, 2011; Husebø et al., 2002; Krieger and Wing, 2002; Stone, 2006). The detrimental effects of bottom fishing activities on deep-water coral ecosystems have been widely demonstrated (Clark et al., 2015). Bottom trawling is known to impact coral communities severely (Althaus et al., 2009; Fosså et al., 2002; Hall-Spencer et al., 2002; Krieger, 2001), but colonies can also get damaged by long lines (Fosså et al., 2002; Mortensen et al., 2005) and are often brought up as bycatch (Breeze et al., 1997; Edinger et al., 2007; Taylor et al., 2013).

Due to longevity and slow growth rates, many benthic deep-water communities, such as corals and sponges, are expected to show slow recovery from fishing impacts (Clark et al., 2015). The recognition of deep-water coral ecosystems as vulnerable habitats has led to increasing efforts in conservation measures in the last 15 years (Brock et al., 2009; Davies et al., 2007; Hall-Spencer et al., 2009; Hourigan, 2009) and multiple areas in the North Atlantic have been closed to destructive fishing practices to protect these habitats (ICES, 2007). Many of these areas were established to protect scleractinian coral aggregations including several reefs of *Lophelia pertusa* in Norwegian waters. In the first deep-water coral

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[1] NECCCA: Northeast Channel Coral Conservation Area.

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conservation area, *Oculina varicosa* was protected from bottom fishing and anchoring off the coast of Florida in 1984 (ICES, 2007; Reed et al., 2007). An example of protection measures for coral gardens is the Northeast Channel Coral Conservation Area (NECCCA) in Atlantic Canada, which harbours dense aggregations of gorgonian corals (Breeze and Fenton, 2007; Mortensen et al., 2005). Coral gardens were added to the OSPAR list of threatened and/or declining species & habitats in 2008, encouraging their consideration in future conservation measures (OSPAR Commission, 2008, 2010). Recent efforts in deep-water coral conservation in the USA include the proposal of the Mid-Atlantic Fishery Management Council in 2015 to protect an area of ~98,000 km^2 from destructive fishing in the U.S. Exclusive Economic Zone.

Effective management of a conservation area requires a management plan with clear objectives; effectiveness of a conservation action should then be evaluated based on the defined targets (Halpern, 2003; Pomeroy et al., 2005). The response of an ecosystem to protection measures is strongly linked to the biology of the targeted species. While some reserves can show increased biomass, density and diversity of species within a few years, the response of slow-growing organisms to protection is expected to require a much longer time frame (Halpern and Warner, 2002). Information on life history traits and recovery times of protected species is essential to ensure a powerful link between biological responses and policy that is often not achieved (Gnanalingam and Hepburn, 2015). Recovery of an impacted system is regarded as the return of that system to conditions similar to the pre-disturbance state (Clark et al., 2015; Williams et al., 2010). Since deep-water ecosystems generally harbour slow-growing and long-lived species (Clark et al., 2015), protection measures need to be long-lasting to ensure recovery and retention of these habitats. In addition to the duration of protection, size, location, extent of ongoing fisheries and enforcement of regulations can influence the success of a conservation area (Edgar et al., 2014). Despite the growing number of conservation measures, long-term studies on the recovery of benthic deep-water communities from fisheries impacts remain scarce (Clark et al., 2015).

To protect dense aggregations of the two dominant octocoral species, *Primnoa resedaeformis* and *Paragorgia arborea*, a 424-km^2 conservation area was established in 2002 by the Canadian government in the Northeast Channel in Atlantic Canada. A "restricted bottom fishing zone" covers ~90% of the NECCCA and is completely closed to bottom fishing gear, while the remaining 10% is a "limited bottom fishing zone", open to bottom long-line fishing with an at-sea observer (ESSIM Planning Office, 2006). The legislation of the NECCCA is provided by the Fisheries Act that prohibits the destruction and detrimental alteration of fish habitat (Department of Justice Canada, 1985). While dense coral aggregations were recorded at depths <500 m prior to the establishment of the NECCCA (Mortensen et al., 2005), distribution patterns of corals in deeper ranges remained largely unknown at that time and the deep boundaries of the conservation area were placed on a precautionary approach.

The deep-water coral communities in the NECCCA were sampled on 3 occasions since 2001 (Lacharité and Metaxas, 2013; Mortensen and Buhl-Mortensen, 2004; Mortensen and Buhl-Mortensen, 2005; Mortensen et al., 2005; Watanabe et al., 2009). Here, we combine these datasets with new data collected in 2014 to explore changes in the deep-water coral assemblages over 13 years. In a resilient ecosystem, we would expect coral aggregations to return to pre-impacted conditions after the fisheries impact ceased (Williams et al., 2010). However, since fishing activities have a long history in the Gulf of Maine and coral bycatch has been reported over the last century (Breeze et al., 1997), the pre-disturbance state of the monitored coral assemblages remains unknown.

To assess whether "highest densities of coral communities are effectively protected" in the NECCCA, we investigated whether: (1) signs of recovery of coral communities were present at different sampling locations 12 years after the fisheries closure; and whether (2) the boundaries of the NECCCA were placed appropriately. Firstly, we monitored shifts in abundance and size of the two dominant octocoral species at depths <700 m over 13 years. Coral size is regarded a fundamental life-history trait and changes over time can provide information on responses of coral populations to disturbances such as from fishing activities (McClanahan et al., 2008). We present the first long-term observations of population dynamics in these protected deep-water octocoral communities. We assumed the observations in 2001 to represent the impacted state of coral communities, while the dataset in 2014 could potentially show first indications of recovery 12 years after the establishment of the NECCCA. Secondly, we analysed coral distribution in the offshore deeper margins of the conservation area (>900 m depth) which have not been studied before, to evaluate the current placement of the NECCCA boundaries. Dives conducted off the southwest boundary of the NECCCA provided information on coral communities immediately outside the conservation area. These data were used to assess the potential of a possible extension of the boundaries of the conservation area.

2. Materials and methods

2.1. Study area and sites

The Northeast Channel is situated between Browns Bank and Georges Bank and provides the only deep passage into the Gulf of Maine (Ramp et al., 1985). Water circulation is largely influenced by tidal currents, where the inflowing water into the Gulf is composed of Warm Slope Water and Labrador Slope Water, while the outflow mainly consists of Maine Intermediate Water (Ramp et al., 1985). Along this Channel multiple canyons are found at depths of ~300 to 1100 m (Twomey and Signell, 2013) that harbour deep-water coral aggregations (Metaxas and Davis, 2005; Mortensen and Buhl-Mortensen, 2004).

Coral communities in and around the NECCCA in the Gulf of Maine were sampled with the ROV ROPOS in August 2001, July 2006, August 2010 and June 2014 (Fig. 1). Data collected in 2001 were used to establish the NECCCA in 2002 (Mortensen et al., 2005) and this is considered the baseline dataset.

Abundance of the two dominant octocoral species, *Primnoa resedaeformis* and *Paragorgia arborea*, was documented at three locations (site 1, site 2, site X; Fig. 2, Table 1) and size frequency distributions at four sites (site 1, 2, X, Z) inside the NECCCA between 26 and 27 June 2014. Mortensen and Buhl-Mortensen (2004) reported coral abundances for ROV dives in 2001, the location of which partially overlapped with our sites 1 and 2; we measured size frequency distributions at these locations using video collected in 2001. Both parameters were also investigated at site X and site Z in 2006 (Watanabe et al., 2009). Details on the methods and data collection can be found in Mortensen and Buhl-Mortensen (2004) and Watanabe et al. (2009).

Additional dives were conducted inside (Fig. 1, Table 2; R1359, 2010) the NECCCA, along the deep boundary (R979, 2006 and R1358, 2010) and outside the NECCCA (R1705, 2014) to determine coral distribution and abundance at depths of 685–1583 m.

In 2014, ROV tracks were reconstructed with 1 Hz positioning data. The Ocean Floor Observation Protocol 3.3.5.i (OFOP) was used to remove obvious outliers and smooth the tracks. Using OFOP, dive tracks were linked to videos and all coral locations were annotated.