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Short and long-term effects of hydraulic dredging on benthic communities and ocean quahog (*Arctica islandica*) populations

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ABSTRACT

The short and long-term effects of hydraulic dredging on ocean quahog (*Arctica islandica*) populations and on non-target organisms were examined in Þistilfjörður Bay, NE Iceland over a five-year period. The overall species richness was low and the fauna was composed of species typical of sandy seabeds characterised by frequent wave-induced disturbances. The initial effects of dredging on the overall benthic community were large. Most taxa were significantly affected by dredging, with abundances sometimes decreasing or increasing by more than 50% immediately after dredging. However, with the exception of the ocean quahog, their recovery was rapid, and most taxa attained similar abundances as in the undisturbed control sediments after three months, and all did so after about a year. The effects of dredging on ocean quahogs were drastic and long-lasting. Of the original ocean quahog biomass before fishing took place, the dredge captured 82%, while a further 11% was lost as a result of mortality due to shell damage and predation. The total direct and indirect loss of ocean quahog biomass within dredged tracks due to fishing was thus 93%. The recovery of ocean quahogs in fished areas was extremely slow. Five years after dredging, the total ocean quahog biomass in tracks had increased from 7% to 26% relative to that in the controls. The proportional increase among ocean quahogs of targeted sizes (>70 mm) was from 2% to 14% over the same period. This study shows that while the longer-term effects of hydraulic dredging on non-target benthic organisms were small, the effects of dredging on ocean quahog densities were drastic, with full recovery expected to take place on decadal time-scales. The impacts of dredging on ocean quahog populations at the scale of the fishery are discussed.

1. Introduction

The detrimental impact of towed demersal fishing gears on target and non-target species and their habitats has been extensively documented worldwide (e.g. Collie et al., 2000; Kaiser et al., 2002). The hydraulic dredge is widely used to target infaunal bivalve species, particularly in the North Atlantic and in the Mediterranean (e.g. Kennish and Lutz, 1995; Morello et al., 2006; Fahy and Carroll, 2007). Within Icelandic waters, a fishery targeting ocean quahogs (*Arctica islandica*) for human consumption with a hydraulic dredge took place between 1995 and 2008 (Thorarinsdóttir and Jacobson, 2005; Thorarinsdóttir et al., 2010). Hydraulic dredging causes a major physical disturbance that destabilises the sediment surface. During hydraulic dredging, sediments are fluidised by a strong jet of seawater that dislodges buried shells. The shells are subsequently captured by a blade that protrudes into the sediment, thus forming a track with depths reported to range from 8 to 20 cm (Meyer et al., 1981; Pranovi and Giovanardi, 1994; Tuck et al., 2000; Hauton et al., 2003; Gilkinson et al., 2003).

The magnitude of the effect of hydraulic dredging on the sedimentary environment and benthic communities can be influenced by various environmental factors such as hydrodynamic regime, substrate type and depth. Hydraulic dredging often takes place in shallow sandy areas characterised by frequent wave-induced disturbances (e.g. tidal currents) where the erosion of tracks is relatively rapid (Meyer et al., 1981; Tuck et al., 2000). The erosion of tracks in deeper waters is expected to be much slower and may mostly take place during storms (Gilkinson et al., 2003, 2005, 2015). During dredging, sediments are suspended (e.g. Meyer et al., 1981) and the finer grain sizes can be dispersed with tidal currents, while the proportion of shell fragments can increase as a result of shell breakage. Intensive hydraulic dredging carried out over a long time period may result in large-scale changes in the benthic community structure (including bivalves of commercial importance) and

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sediment properties (Pranovi and Giovanardi, 1994; Tuck et al., 2000; Chícharo et al., 2002; Morello et al., 2006; Duineveld et al., 2007; Fahy and Carroll, 2007). Similarly, the effects of hydraulic dredging on benthic communities and habitats may become greater with increasing depth and/or decreasing hydrodynamic forcing, e.g. frequency of wave-induced sediment disturbances. Studies carried out in shallow waters where the fauna is likely to be highly adapted to wave-induced disturbances, such as those caused by storms (e.g. Constantino et al., 2009; Hiddink, 2003; Wijnhoven et al., 2011), have mostly demonstrated minor impacts. The impacts of dredging in a more benign hydrodynamic regime, such as in sheltered lagoons (Pranovi and Giovanardi, 1994) and in deeper waters (Gilkinson et al., 2005) have been shown to be greater. As an example, Gilkinson et al. (2005) reported a 42% decrease in the abundance of non-target organisms following dredging. The magnitude of the dredge impacts can also be related to the dredge size and the pressure of the water jet. For example, the dredge used in the Gilkinson et al. (2003, 2005) studies was about 60 times heavier than the one used by Goldberg et al. (2012, 2014) and Meseck et al. (2014).

Most dredge impact studies have examined the short-term recovery rates of benthic organisms, i.e. three months or less (Hall et al., 1990; Pranovi and Giovanardi, 1994; Tuck et al., 2000; Morello et al., 2005), but few have followed recovery processes for a year or longer (Ismail, 1985; Gilkinson et al., 2005, 2015; Wijnhoven et al., 2011; Goldberg et al., 2012). The pattern emerging from these studies is that the recovery of benthic organisms within dredged plots was generally rapid, apart from large-bodied infaunal bivalves, of which most were of commercial importance. Studies that sampled frequently after fishing reported rates of full recovery to range from days to a few weeks (Hall et al., 1990; Tuck et al., 2000), while Pranovi and Giovanardi (1994) reported that full recovery did not take place within the two-month study period.

A number of factors can influence the initial depletion rates of commercially targeted bivalve species; in particular, capture efficiency and selectivity of the dredge, mortality of damaged shells and displacement of shells out of the track. The hydraulic dredge generally has high capture efficiency and selectivity. As an example, the capture efficiency was estimated to be 92% for large (107.5 mm) ocean quahogs in Icelandic waters (Thorarinsdóttir et al., 2010). The dredge can inflict damage on those shells that are not captured and thus cause indirect fishing mortality (Caddy, 1973; Gaspar et al., 1998; Moschino et al., 2003). The magnitude of the shell damage is highly species specific (Hauton et al., 2003) and depends on factors such as shell strength, size, sediment characteristics and on gear settings, e.g. the pressure and the position of the dredge teeth (Gaspar et al., 1998; Moschino et al., 2003; Vasconcelos et al., 2011). During dredging shells can be dislodged and/or displaced out of the track. The survival of these shells can depend on their reburial ability (Coffen-Smout and Rees, 1999; Hauton et al., 2003) and on the predation pressures in the area (Ramsay et al., 1998; Ramsay and Kaiser, 1998; Robinson and Richardson, 1998). The recovery of large-bodied infaunal bivalves in dredged tracks is expected to take a very long time as many of these share life-history characteristics such as slow growth and high age at maturity (e.g. Kennish and Lutz, 1995). Gilkinson et al. (2005, 2015) examined *in situ* the recovery patterns of *A. islandica*, *Cyrtodaria siliqua*, *Serripes groenlandicus* and *Mactromeris polynyma*, all of which were of commercial importance. They showed that dredging caused a substantial (up to 67%) reduction in the biomass of these bivalves. The bivalves showed a minor recovery at the end of the study, ten years after dredging (Gilkinson et al., 2005, 2015).

The ocean quahog (*A. islandica*) is the longest-lived non-colonial animal known to science for which the age at death can be accurately evaluated (Ridgway and Richardson, 2011) with the oldest individual to date aged as 507 years old (Butler et al., 2013). The growth rate of juvenile ocean quahogs is relatively fast, but can be highly variable (e.g. Murawski et al., 1982; Kennish et al., 1994; Witbaard et al., 1997; Beirne et al., 2012). The growth rate decreases with age, from ~2 mm year^{-1} for ~20 year old quahogs to ~0.5 mm year^{-1} for quahogs that are ~50 years old (Kilada et al., 2007). The earliest age at which ocean quahogs mature in Icelandic waters is 10 and 13 years for males and females respectively (Thorarinsdóttir and Steingrímsson, 2000). Recruitment of ocean quahog and/or degree of postlarval mortality appear to be highly variable (Murawski et al., 1982; Powell and Mann, 2005) and may be related to seawater temperature (Harding et al., 2008). This combination of life-history traits makes this species very sensitive to fishing.

A manipulative field experiment was used to test hypotheses about the short (0–3 months) and long-term (1–5 years) effects of hydraulic dredging on the abundance, biomass and size distributions of the ocean quahog and on community structure, abundance and diversity of non-target organisms. It was expected that the recovery of non-target species would be relatively rapid, and samples were therefore collected in dredged and control locations immediately and three months after dredging. Considering the slow growth rate of ocean quahogs, their recovery was followed over a five-year period.

2. Material and methods

2.1. Study site

The study site was located in Þistilfjörður Bay, NE Iceland (66°10′N, 15°23′W) at around 10 m depth. Sediments consisted of very tightly packed fine sand (66% with grain size between 125 μm and 250 μm). The site can be subject to severe storms, especially at times of strong and persistent northerly winds, causing sediment transport and in some cases dislodgement of ocean quahogs (Thorarinsdóttir et al., 2009).

2.2. Experimental design

The short and long-term effects of hydraulic dredging were examined with a field experiment. In April 2003, three tows separated by ~150 m were taken with a hydraulic dredge, using the commercial fishing vessel ÞH-362 Fossá (~290 GT), which targeted ocean quahogs off N and NE Iceland over the period 2001–2008. The hydraulic dredge (735 × 150 × 365 cm in l x h x w respectively and 9 GT in weight) was fitted with an adjustable cutting blade beneath (305 cm wide and set at 8 cm depth). The bar spacing in the dredge was 33 mm, and the pressure of the seawater obliquely directed towards the seabed in front of the dredge was 7.5 bars. All the operational factors, such as towing speed (~2.4 knots), tow length (~0.3 nmi), and the pressure of the water jet exerted towards the seabed (~8 bars), were similar for all tows.

To ensure that the divers could locate the tracks easily, the small research boat EA-49 Einar í Nesi (9.6 GT) followed ÞH-362 Fossá during dredging and deployed buoys at the start and end of each of the dredged tracks. Afterwards, the divers inserted five metal poles, separated by 6 m, into the sediment along each side of the track. The area within each two pairs of metal poles (~3 m in width and ~6 m in length, i.e. ~18 m^2) represents a single sampling segment. Samples were collected immediately after dredging in April 2003, and subsequently in July 2003, May 2004, May 2005 and May 2008. A single segment was sampled at each occasion in a successive manner to ensure that the same area was not sampled more than once.