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Impact on demersal fish of a large-scale and deep sand extraction site with ecosystem-based landscaped sandbars

Maarten F. de Jong [a, *], Martin J. Baptist [a], Ralf van Hal [a], Ingeborg de Boois [a], Han J. Lindeboom [a], Piet Hoekstra [b]

[a] IMARES Wageningen UR – Institute for Marine Resources & Ecosystem Studies, Department of Ecosystems, PO Box 1790, AD Den Burg, The Netherlands
[b] Institute for Marine and Atmospheric Research Utrecht, Faculty of Geosciences, Utrecht University, PO Box 80.115, 3508 TC Utrecht, The Netherlands

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ABSTRACT

For the seaward harbour extension of the Port of Rotterdam in the Netherlands, approximately 220 million m^3 sand was extracted between 2009 and 2013. In order to decrease the surface area of direct impact, the authorities permitted deep sand extraction, down to 20 m below the seabed. Biological and physical impacts of large-scale and deep sand extraction are still being investigated and largely unknown. For this reason, we investigated the colonization of demersal fish in a deep sand extraction site. Significant differences in demersal fish species assemblages in the sand extraction site were associated with variables such as water depth, median grain size, fraction of very fine sand, biomass of white furrow shell (*Abra alba*) and time after the cessation of sand extraction. Large quantities of undigested crushed white furrow shell fragments were found in all stomachs and intestines of plaice (*Pleuronectes platessa*), indicating that it is an important prey item. One and two years after cessation, a significant 20-fold increase in demersal fish biomass was observed in deep parts of the extraction site. In the troughs of a landscaped sandbar however, a significant drop in biomass down to reference levels and a significant change in species assemblage was observed two years after cessation. The fish assemblage at the crests of the sandbars differed significantly from the troughs with tub gurnard (*Chelidonichthys lucerna*) being a Dufrêne-Legendre indicator species of the crests. This is a first indication of the applicability of landscaping techniques to induce heterogeneity of the seabed although it remains difficult to draw a strong conclusion due the lack of replication in the experiment. A new ecological equilibrium is not reached after 2 years since biotic and abiotic variables are still adapting. To understand the final impact of deep and large-scale sand extraction on demersal fish, we recommend monitoring for a longer period, at least for a period of six years or even longer.

1. Introduction

The demand for marine sand in the Netherlands and worldwide is strongly increasing. In the Netherlands, approximately 24 million m^3 sand is used annually for coastal nourishments and for construction. An increase of annual coastline nourishments of up to 40-85 million m^3 to counteract effects of future sea level rise is expected (Deltacommissie, 2008). For the seaward expansion of the Port of Rotterdam (Maasvlakte 2) approximately 220 million m^3 of sand was extracted between 2009 and 2013 with an average extraction depth of 20 m. In general, only shallow sand extraction down to 2 m below the seabed and beyond the 20 m isobath is allowed in the Netherlands (IDON, 2005; V&W, 2004). For Maasvlakte 2 though, the Dutch government permitted sand extraction deeper than the common 2 m, primarily to reduce the surface area of direct impact.

Fish assemblages at North Sea scale are mainly influenced by bottom water temperature, bottom water salinity, tidal stress and water depth (Callaway et al., 2002; Reiss et al., 2010). Furthermore, fish assemblages are linked to biotic and abiotic habitat characteristics and meso-scale bedforms (Ellis et al., 2011; Sell and Kröncke, 2013). Ellis et al. (2011) found that species richness of infauna, epifauna and fish was larger in the silty troughs of sandbanks off the coast of the UK than on the crests.

Large-scale sand extraction was shown to have a negative impact on fish in the Yellow Sea (Hwang et al., 2013), a decline of more than 70% of the total number of fish and the number of species (Son and Han, 2007) and direct and indirect damages to commercial fisheries were observed (Kim and Grigalunas, 2009). On the other hand,

* Corresponding author.
E-mail address: maarten.dejong@wur.nl (M.F. de Jong).

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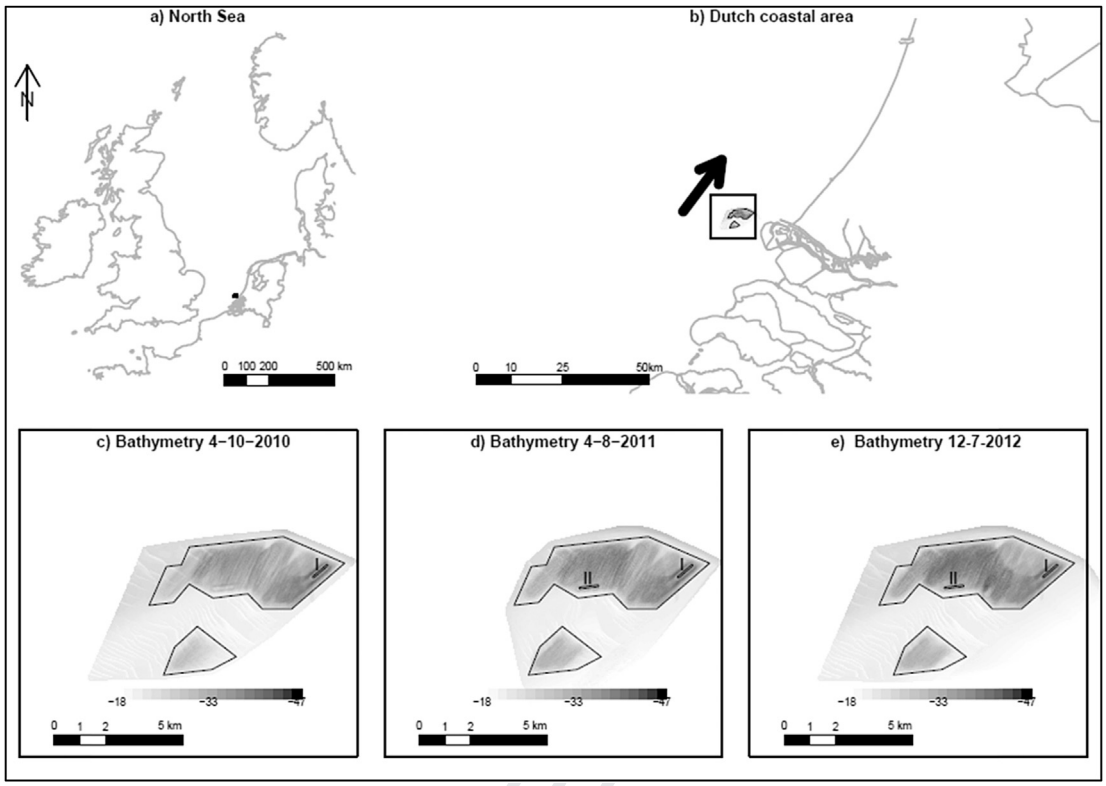

Fig. 1. a) North Sea, b) Dutch coastal area with Maasvlakte 2 sand extraction site and harbour extension in front of the Port of Rotterdam, the arrow denotes the residual tidal current, c) bathymetry of sand extraction site (date 4 October 2010) with one landscaped sandbar parallel to the tidal current (I). d-e) Sand extraction site (dates 4 August 2011 and 12 July 2012) with two landscaped sandbars, one parallel (I) and one oblique to the tidal current (II). Data were derived from bathymetric multibeam surveys of the dredging companies.

aggregate extraction may also lead to new habitats and may favour macrozoobenthos and fish (Desprez, 2000).

Ecosystem-based landscaping techniques are not commonly used to reduce the impact of sand extraction. In the UK, gravel-seeding techniques were tested to restore the seabed after gravel extraction (Cooper et al., 2011). In the Maasvlakte 2 sand extraction site, two sandbars were artificially created by selective dredging, copying naturally occurring meso-scale bedforms to increase habitat heterogeneity and thereby possibly increasing post-dredging benthic and demersal fish species richness and biomass. In this study, we test the hypothesis that deep and large-scale sand extraction and ecosystem-based landscaping approaches will lead to differences in fish assemblage and we are aiming to answer the following questions:

- Are there significant differences in fish species assemblage between reference area and sand extraction site, and within the extraction site?
- Are there significant temporal differences in fish assemblage, macrozoobenthos and environmental variables during the monitoring campaign?
- Which environmental variables determine the differences?
- Are ecosystem-based landscaping techniques landscaping techniques feasible and effective in influencing fish assemblages?

2. Methods

2.1. Study area

The Maasvlakte 2 sand extraction site is situated in front of the Port of Rotterdam, the Netherlands, outside the 20 m depth contour (Fig. 1). The sand extraction site is 2 km long, 6 km wide with an average extraction depth of 20 m at an initial water depth of approximately 20 m below average sea level. Approximately 220 million m^3 sand was extracted between 2009 and 2013, of which 170 million m^3 in the first two years (Borst and Vellinga, 2012).

Two sandbars were created in the extraction site to investigate the applicability of ecosystem-based landscaping in sand extraction projects (Figs. 1 and 2). One sandbar (I), parallel to the tidal current, was left behind in the seabed in spring 2010. This parallel sandbar has a length of 700 m, a width at the crest of 70 m and slopes of 140 m length (Fig. 2). The crest of the sandbar is located at a water depth of 30 m and the troughs are more than 40 m deep. In 2011, the second sandbar (II) was completed with an orientation oblique to the tidal current. The length and width are similar to the parallel sandbar but, due to time constraints, the difference in depth between crest and trough is less pronounced. The crest is situated at a water depth of 28 m and the northern trough is 36 m deep. A narrow and 32 m deep trench separates the crest from the slope of the sand extraction site. The volume of each sandbar is approximately 1.25 million m^3 with slopes of 1:7–1:10.

During our surveys in 2011 and 2012, two trailer suction hopper dredgers were active in the centre of the sand extraction site, extracting approximately 2 million m^3 marine sand per week. The water depth increased from 33 m to approximately 40 m (Fig. 1) but the areas near the landscaped sandbars remained un-dredged after completion.

2.2. Fishing methods

A commercial fishing vessel was used, the Jan Maria, GO 29, with a length of 23 m, less than 300 horsepower and equipped with a

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