# The future of sand extraction in the Dutch part of the North Sea

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The demand for marine sand in the Netherlands and internationally is still increasing. In the Netherlands, 24 million m³ marine sand is used yearly for coastal nourishments and as filling sand which may increase up to 85 million m³. To guarantee sufficient supply of marine sand in the intensively used coastal zone, the authorities are now promoting sand extraction depths over 2m. Effects of deep sand extraction, however, are still largely unknown.

We developed ecosystem-based design rules for borrow pits based on insights from several short-term studies prior and after the 200 million m³ and 20m deep sand extraction operation for the harbour enlargement Maasvlakte 2 in the intensively used area of the Dutch coastal zone in front of Port of Rotterdam. We investigated two types of benthic assemblages, infaunal assemblages sampled with a boxcorer and epifaunal assemblages sampled with a bottom sledge. A fish survey was conducted with a commercial fishing vessel equipped with a standard commercial 4.5m beam trawl with a mesh size of 80mm.

Macrozoobenthos and demersal fish biomass increased manifold and species composition changed significantly. Next to changes in macrozoobenthos, sediment characteristics also significantly changed in the deepest parts. Macrozoobenthic species composition and biomass correlates with time after cessation of sand extraction, sediment and hydrographical characteristics.

To develop ecosystem-based design rules for borrow pits, sediment characteristics are not present but bed shear stress can be calculated with extraction depth and depth-averaged peak flow velocity. Based on the bed shear stress, two assemblages were distinguished (*Abra alba* below 0.37 N $m^{-2}$ and *Echinoidea* spp. – *Phoronida* sp. assemblage above 0.49 $Nm^{-2}$).

We suggest an ecosystem-based borrow pit design, with bed shear stress values around 0.35 N $m^{-2}$, resulting in the occurrence of the two mentioned assemblages. For the Maasvlakte 2 borrow pit, extraction depth would be 12m with a post-dredged water depth of ~32m. The ecosystem-based borrow pit design rules can also be used for comparable regions but ecological data from sites with low shear stress values (borrow pits) may be prerequisite.

Combining the results of macrozoobenthic species composition and sedimentation rates in the 20m deep borrow pit and a natural deep seafloor crater leads to the conclusion that benthos is not returning to pre-dredged conditions within decades. We recommend ongoing monitoring including sedimentation rate and oxygen measurements since significant changes in epifauna and demersal fish occurred in the deepest parts of the borrow pit.