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Impact evaluation of marine aggregate extraction through adaptive monitoring of bottom shear stress in bedform areas

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Abstract

Dedicated monitoring programmes are needed for the evaluation of the effects of the exploitation of non-living resources on the territorial sea and the continental shelf. Related to physical impacts, hydrodynamics and sediment transport, together with sedimentological and morphological evolution, need investigation. Overall aim is to increase process and system knowledge of both natural and exploited areas, with a particular focus on the compliancy of extraction activities with respect to European Directives (e.g., European Marine Strategy Framework Directive and Habitat Directive). More specifically assessments are needed of changes in seafloor integrity and hydrographic conditions, two descriptors to define Good Environmental Status within Europe's Marine Strategy Framework Directive.

An important parameter is the bottom shear stress, with knowledge needed on both natural and anthropogenically-induced variability. Bottom shear stress measurements are used for the validation of numerical models, necessary for impact quantification in the far field. Extensive data-model integration is critical for adequate assessments of the status of the marine environment, a prerequisite for sustainable use of living, and non-living resources.

1. INTRODUCTION

Mineral and geological resources can be considered to be non-renewable on time-scales relevant for decision-makers. During the last decade, socio-economic demands for marine aggregate resources in the North-East Atlantic or OSPAR region have increased at an unprecedented pace. During the past few years, hundreds of millions m^3 of offshore sand and gravel have been extracted for coastal maintenance, harbour extensions and onshore industrial use. Future aggregate demands will be even higher. Increasing volumes of nourishment sand are needed as accelerating sea-level rise will leave our coastlines ever more vulnerable. In addition, vast quantities of sand and gravel will have to be extracted to realize the large infrastructural works that are the key components of many visions on coastal zone and offshore development.

Sustainable use of marine resources is required and is inevitably linked to good environmental status (GES) of the marine environment. This is the 2020 goal of the Marine Strategy Framework Directive (MSFD, 2008/56/EC). Furthermore, following the Habitat Directive (92/42/EEC), Natura 2000 sites have been implemented in the marine environment. Appropriate assessments are needed of any plan or project that may affect such sites.

To allow monitoring of the evolution towards GES, a series of descriptors have been defined. Related to physico-chemical seabed attributes, descriptor 6 on seafloor integrity and descriptor 7 on hydrographic conditions are relevant in the context of aggregate extraction. GES for seafloor integrity refers to the structure and functions of the ecosystems that need safeguarding, without adversely affecting benthic ecosystems, whilst GES for hydrographic conditions means that permanent alteration of hydrographical conditions does not adversely affect marine ecosystems. 'Not adversely affected' can be interpreted as meaning that impacts may be occurring, but all impacts are sustainable such that natural levels of diversity, productivity, and ecosystem processes are not degraded (Rice et al. 2012). Hence, there is a clear need for methodologies and tools that allow quantification of natural and man-made changes that, in combination with geological knowledge bases, define sustainable exploitation thresholds. Only then assessments can be made whether or not recovery from perturbations will be rapid and secure, and whether changes will remain within the range of natural variation.

For the first cycle of MSFD (2012-2018), Belgium put forward some physical indicators that should allow monitoring progress towards good environmental status (Belgische Staat 2012).

(1) For seafloor integrity, they are related to particular sediment classes (cf. predominant habitat types), of which the spatial extent and distribution should remain equal, or at least within its margins of uncertainty (Van Lancker & van Heteren 2013, for a discussion). Furthermore, the ecological value of gravel beds is recognized and an indicator is proposed that stipulates that the ratio of the surface of hard substrate (i.e., surface colonized by hard substrata epifauna) against the ratio of soft sediment (i.e., surface on top of the hard substrate that prevents the development of hard substrata fauna), does not show a negative trend. This relates directly to exploitation-induced increases in turbidity that may lead to siltation in areas where those gravel beds occur.

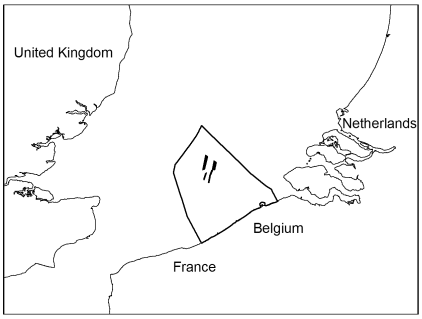
(2) Bottom shear stress is chosen as an indicator to assess changes in hydrographic conditions. Using validated mathematical models, it is calculated over a 14-days spring-neap tidal cycle. An impact should be evaluated when one of the following conditions is met: (i) There is an increase of more than 10% of the mean bottom shear stress; (ii) The variation of the ratio between the duration of sedimentation and the duration of erosion is beyond the "-5%, +5%" range; (iii) The impact under consideration should remain within a distance equal to the square root of the area occupied by this activity and calculated from the inherent outermost border.

All developments need compliance with existing regulations (e.g., EIA, SEA, and Habitat Directive Guidelines) and legislative evaluations are necessary in such a way that an eventual potential impact of permanent changes in hydrographic conditions is accounted for, including cumulative effects. This should be evaluated with relevance to the most suitable spatial scale (ref. OSPAR common language).

This paper outlines the monitoring programme that should allow quantifying the effects of marine aggregrate extraction and evaluating the compliancy with respect to European Directives. The natural dynamics of the seabed, and of its bedforms in particular, complicate the debate. The monitoring programme has started in 2013 with pre-investigations in 2012.

2. STUDY AREA

Over a 10-yrs period intensive extraction of marine aggregates (up to 2.9 million m³ over 3 months) is allowed on the Hinder Banks, a sandbank complex located 40 km offshore in the Belgian part of the North Sea (BPNS). Depths are from 5 m to 30 m (Fig. 1). The sandbanks are superimposed with a hierarchy of dune forms, often more than 6 m in height. The channels in-between the sandbanks reach 40 m of water depth. Such intensive extraction activities are new practice in the BPNS, for which the environmental impact is yet to be determined. Furthermore, a Habitat Directive Area is present at a minimum of 2.5 km from the southernmost exploitation sectors. In this area, highest biodiversity is found in the troughs of barchans dunes (Houziaux et al. 2008).



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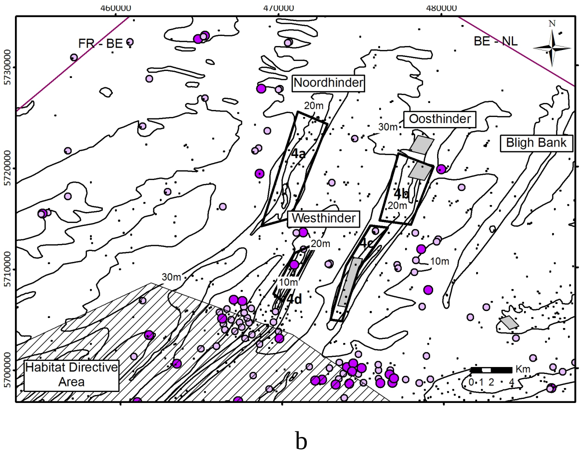

Figure 1. The Belgian part of the North Sea (a) and the area of the Hinder Banks (b), where intensive marine aggregate extraction is allowed in 4 sectors (black polygons). A Habitat Directive Area is present at a minimum of 2.5 km from the southernmost sectors. The size of the dots represents relative amounts of gravel with a minimum of 20 %. Borders with France (FR-BE) and the Netherlands (BE-NL) are indicated. In the grey shaded areas repetitive multibeam recordings.

3. MONITORING PROGRAMME

The monitoring programme is steered towards the testing of impact hypotheses, that are based on 30-yrs of extraction practices and its related research on the effects (Van Lancker et al. 2010, for an overview):

(1) Seabed recovery processes are very slow; (2) Large-scale extraction leads to seafloor depressions; these do not impact on the spatial connectedness of habitats (MSFD descriptor 6); (3) Impacts are local, no far field effects are expected; (4) Resuspension, and/or turbidity from overflow during the extraction process, will not lead to an important fining of sediments (e.g., siltation); (5) Marine aggregate extraction has no significant impact on seafloor integrity, nor it will significantly lead to permanent alterations of the hydrographical conditions (MSFD descriptor 7) (i.e., no change of sediment transport pathways); (6) Cumulative impacts with other sectors (e.g., fisheries) are minimal; and (7) Large-scale extraction does not lead to changes in wave energy dissipation that impact on more coastwards occurring habitats.

A tiered approach is proposed consisting of in-situ measurements and modelling. Critical is to assess potential changes in hydrographic conditions, as a consequence of multiple seabed perturbations (e.g., depressions) and their interactions. In short, current measurements along transects are needed to depict spatial variability over the sandbank areas, in combination with quantification of turbidity to assess changes due to the release of fines throughout the extraction process. Consequently, insight is needed in the dispersion of the fines and the probability of siltation in the nearby Habitat Directive area.

3.1 In-situ measurements

Three campaigns a year are aimed at and include: (1) Transect-based measurements (Fig. 2) of the full three-dimensional current velocity and direction, together with turbidity based on the acoustic backscatter over 13-hrs cycles (hull-mounted acoustic Doppler current profiler). (2) Very-high resolution acoustic measurements (Kongsberg-Simrad EM3002 multibeam, MBES) to obtain depth, backscatter, and water column data. Repetitive MBES measurements allow identifying erosion and/or deposition areas, estimating bedload transport pathways and magnitude from the asymmetry and rate from the migration of sand dunes, and assessing seabed sediment changes. (3) Water column measurements at fixed stations, over 13 hrs windows, to study temporal variations in salinity, temperature and depth (CTD), turbidity (optical backscatter sensor, OBS), and particle size distributions (Sequoia type C 100 X Laser In-Situ Scattering and Transmissometry, LISST). Water samples are taken for calibration of the OBS measurements.

To investigate near-bottom processes, it is envisaged to use a benthic tripod, instrumented with sensors dedicated to the measurement of currents, using ADP (Acoustic Doppler Profiler) and ADV (Acoustic Doppler Velocimeter) instruments, and turbidity (OBS). Bottom shear stress will be calculated (Francken & Van den Eynde 2010). At least, recordings of 14 days spring/neap tidal cycles are aimed at.

Seabed sediment samples are taken in function of increasing the reliability of sediment maps that serve as input to sediment transport models (e.g., bottom roughness). Changes in seabed sediment samples (e.g., siltation) are evaluated.

Optimal positions of the in-situ measurements are based on the results of the acoustic measurements (ADCP and MBES), and model results.

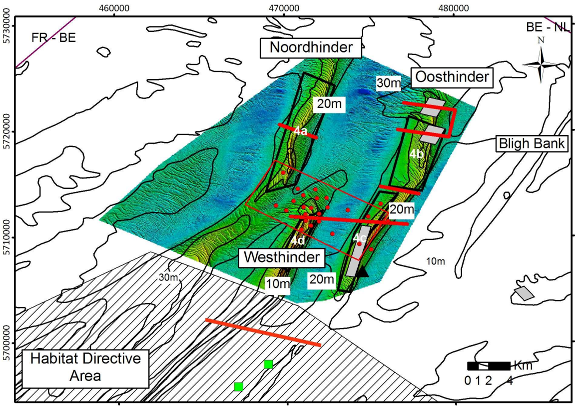

Figure 2. Sandbanks and troughs in the area of the Hinder Banks. Cross-sectional lines show the locations of ADCP profiling. Along the transects, water sampling and vertical profiling is performed. Repetitive MBES measurements are performed in the grey zones and within the rectangle covering the central zone of the Hinder Banks, together with sediment samples. The triangle indicates the position of longer-term measurements of sediment processes. Small rectangles in the Habitat Directive area are the locations of ecologically valuable gravel beds. Background bathymetry: FPS Economy, Self-Employed and Energy.

3.2 Quantitative model validation

Measurements will feed into numerical models (250 m x 250 m grid resolution) for conducting impact assessments under various scenarios of extraction activities.

Hydrodynamic models (OPTOS-BCZ, Luyten 2010), driving sediment transport and advection-diffusion models, need validation to allow quantification of their accuracy, critical to detect changes in time. Statistical analyses of the differences between model results and observations will be executed.

Sediment transport models (MU-SEDIM, Van den Eynde et al. 2010) need refinement: e.g., bottom shear stress calculated with the numerical model, will be compared with the bottom shear stress, derived from the ADV and ADP measurements (see above). An adjustment of the modelled shear stress to the observed shear stresses will be executed, by fitting the bottom roughness. Using all available data, an analysis of the variability of the resulting bottom roughness, as a function, amongst others, of grain-size distribution, will be executed. Furthermore the predicted sediment transport magnitude and directions will be compared to the sediment transport estimates, derived from sand dune migrations and asymmetries.

Advection-diffusion sediment transport models (MU-STM, Fettweis & Van den Eynde 2003; Van den Eynde 2004) will be refined allowing quantifying erosion and deposition of fine-grained material and (fine) sand in the water column. Results will be compared with the measurements and observations along areas where the probability of settling of finer sediments is highest. The significance of increases in turbidity will be determined from statistical analyses of the longer time series of turbidity (from benthic lander).

4. DISCUSSION

As stated in the introduction, the monitoring programme should allow quantifying the impacts of marine aggregate extraction and evaluating its compliancy with European Directives. The latter is relatively new and the monitoring requires extensive testing of the effectiveness and sensitivity of the indicators that should allow assessing progress towards good environmental status. For assessing changes in hydrographic conditions, the ranges in calculated bottom shear stress will identify whether or not an impact should be further evaluated. If this is the case, it is still acceptable as long as the impacted area remains within a certain buffer. For the exploitation in the Hinder Banks region this buffer is indicated in Fig. 3. Clearly, the area of impact can have significant dimensions. Following this concept, no impact is allowed in the Habitat Directive area, just south of the exploitation zone. Whether or not this indicator would be an early warning, preventing adverse effects on the ecosystem, remains to be investigated.

Furthermore, the influence of varying bedform properties and dynamics is not clear yet.

Calculation of bottom shear stresses is far more complicated in bedform areas, and can potentially not be modelled with conventional techniques. The dynamics of large bedforms and the relation with ecological functions they can provide is poorly studied. According to their setting, dimensions and morphology, some of them are more effective in trapping fine sediments (Van Lancker et al. this volume). In many cases such areas host a richer biodiversity. Whether or not exploitation-induced siltation will adversely affect the ecosystem requires further investigation and debate.

Hence, monitoring programmes should be adaptive, with approaches that are adjustable following external input and new insights. It is a learning process with the aim of reducing uncertainties and allowing calculation of risks when certain environmental goals are not reached (Laane et al. 2012). Extensive data-model integration is needed, that should allow showing the societal relevance of the measures that are proposed to monitor progress towards good environmental status of the marine environment.

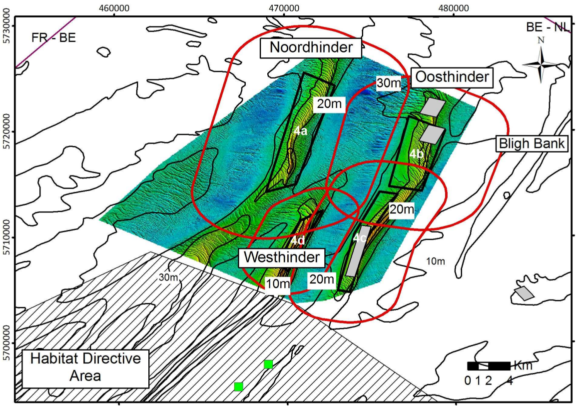

Figure 3. Buffer of acceptable change in bottom shear stress in the Hinder Bank region where marine aggregate extraction is allowed in 4 sectors. Calculations according to Belgische Staat (2012).

5. CONCLUSIONS

A monitoring programme is proposed that should allow quantifying the impacts of marine aggregate extraction and evaluating its compliancy with European Directives. Most importantly, monitoring should allow assessing progress towards good environmental status. This is relatively new and requires extensive testing of effectiveness and sensitivity of indicators. One of the indicators is bottom shear stress and should allow evaluating changes in hydrographic conditions due to human impact. It is stipulated that extensive data-model integration is needed for adequate assessments of the status of the marine environment, a prerequisite for sustainable use of living and non-living resources.

6. ACKNOWLEDGMENT

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