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Assessment of the physical disturbance of the northern European Continental shelf seabed by waves and currents

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ABSTRACT

Natural seabed disturbance was quantified by estimating the number of days in a year that movement of the seabed occurred due to waves and currents. Disturbance over gravel substrates was based on the concept of a critical threshold for bed movement. For mud substrates disturbance was assessed on the basis of bed failure under extreme hydrodynamic stress. For sand beds the disturbance frequency was calculated by reference to the predicted occurrence of small scale bedforms using established relationships for estimating ripple and megaripple height. The method was applied to the northern European Continental Shelf (48°N to 58.5°N and 10°W to 10°E) using modelled annual wave and current forcing with a temporal resolution of one hour and spatial resolution of approximately 11 km. Highest levels of disturbance occurred in areas of high tidal stress where dune/megaripple type bedforms were predicted and in shallow regions exposed to waves with large fetch. However, the detailed distribution of disturbance showed a complex relationship between water depth, tidal stress, wave fetch and grain size. An assessment of the uncertainty in the results was made by use of a simple Monte Carlo approach. In most locations this indicated a large uncertainty in disturbance frequency values suggesting that present predictive relationships need improvement if assessments of natural disturbance are to be made with confidence. Nevertheless the results give a broad understanding of the location and intensity of natural physical bed disturbance and the ability to compare the relative intensity between different regions. This has applications to management of the seabed where human impacts have to be assessed in the context of the underlying natural disturbance. Recommendations are given for further research that might help decrease the uncertainty in natural disturbance prediction.

1. Introduction

Physical disturbance of the seabed by waves and currents is an important factor influencing habitat and species distributions (Hall, 1994; Kostylev and Hannah, 2007), benthic biogeochemical functioning (Trimmer et al., 2005), and the transport and potential burial of pollutants (Kershaw et al., 1999). It also provides the background against which the impact of human-induced disturbance needs to be assessed. In this paper a methodology is presented for quantifying natural seabed disturbance in terms of the number of days in a year physical disturbance occurs to a given sediment depth. The agents of natural disturbance are taken to be waves, tides and wind-driven currents and natural 'disturbance' is defined as movement of the seabed sediment resulting from hydrodynamic stress.

Natural seabed disturbance has been considered by a number of workers, mainly in the context of assessing anthropogenic impacts. Thus De Alteris et al. (1999) consider the proportion of time the seabed undergoes natural sediment movement in relation to trawling activity and the rate at which beam trawl scars were removed. Following a slightly different approach, Brown et al. (2005) suggest the relative impact of wave-induced seabed disturbance will be greater than that of beam trawling disturbance when the near bed orbital velocity magnitude exceeds typical trawl speeds. Natural disturbance is also important in the definition and classification of marine habitats. Wave and current modelling was used in Hemer (2006) to derive maps of the frequency and magnitude of bed stress on the Australian continental shelf. Further developments in the same region (Hughes et al., 2010; Harris and Hughes, 2012) consider the frequency of extreme bed stress events and the identification of ecologically disturbed regions, with application to habitat classification and biodiversity measures. In a similar application, Kostylev and Hannah (2007)

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combine a number of factors, including total wave-current bed stress to characterise disturbance and define habitat types for the Scotian Shelf and Bay of Fundy.

The approach taken in this study partly follows Hemer (2006) in using wave and current modelling to predict frequency and magnitude of hydrodynamic stress. However, rather than focussing simply on bed stress, consideration is also given to the seabed response to this stress. Over sandy sediments this response is characterised by the formation of small scale bedforms where the bedform height can be used to define a depth of disturbance. For gravel substrates the critical erosion stress of the underlying sediment is taken into account. For muddy sediments, large scale bed failure related to extreme hydrodynamic bed stress is used as the criteria for disturbance. Since the methodology is based on a synthesis of existing work on wave and current interaction with the seabed, no independent validation of the prediction methods is presented. However, an assessment of the uncertainty in the results is made using a Monte Carlo approach with probability distribution derived from a subjective assessment of the uncertainty of the empirical relationships used. The methodology was applied to the north European continental shelf including the North Sea, English Channel, Irish and Celtic Seas.

The principal output is an estimate of the number of days in a year disturbance occurred (and for sandy substrates, to what depth below the sediment surface). This is expressed in terms of a median value together with an indication of the degree of uncertainty based on the Monte Carlo type simulations. For sandy sediments an additional result is a prediction of the occurrence of different bedform types with an indication of which are the most important for disturbance in a given location. Finally, an attempt is made to identify gaps in knowledge based on the experience of undertaking this study.

The results allow a broad understanding of the location and frequency of physical bed disturbance due to natural hydrodynamic processes. Such information may be useful for marine management if, for example, it is decided to confine disruptive activity to areas with higher levels of natural disturbance (on the assumption that these may be more resilient to anthropogenic disturbance) or, for seabed remediation, to focus on sites with little natural disturbance (as these may take longer to return to a recovered state without such intervention). Applications include the assessment of fishing impacts (Diesing et al., 2013), criteria for the selection of marine protected areas (FSBI, 2001), definitions of seabed integrity under the European Marine Strategy Framework directive (MSFD), as well as decisions on the licensing of the seabed for aggregate extraction (Eggleton et al., 2011), offshore energy development or the disposal of dredged material.

2. Methods

2.1. Hydrodynamics

Wave and currents were modelled on the European continental shelf in the region between 48°N and 58.5°N and 10°W to 10°E with a grid resolution of approximately 11 km (1/6 degree east-west, 1/9 of a degree north-south). Seabed sediment type and grain size information were available for a more limited area restricting the region for which disturbance calculations could be carried out (Fig. 1). Simulations used here were for the year 2008. Depth mean tidal and wind-driven currents were calculated using the POLCOMS model (Holt and James, 2001) forced with 15 tidal constituents (Q1, O1, P1, S1, K1, 2N2, μ2, N2, ν2, M2, L2, T2, S2, K2, M4) and hourly wind and pressure at 12 km resolution from the UK meteorological office mesoscale atmospheric model. Using the same meteorological forcing, the WAM spectral wave model (Osuna and Wolf, 2004) was used to provide the root mean square (RMS) wave orbital velocity, mean zero crossing wave period (T_z), and wave direction at the bed. Both current and wave information were sampled at hourly intervals for subsequent calculations. Further details on model forcing and validation can be found in a companion paper (Bricheno et al., submitted). Validation consisted

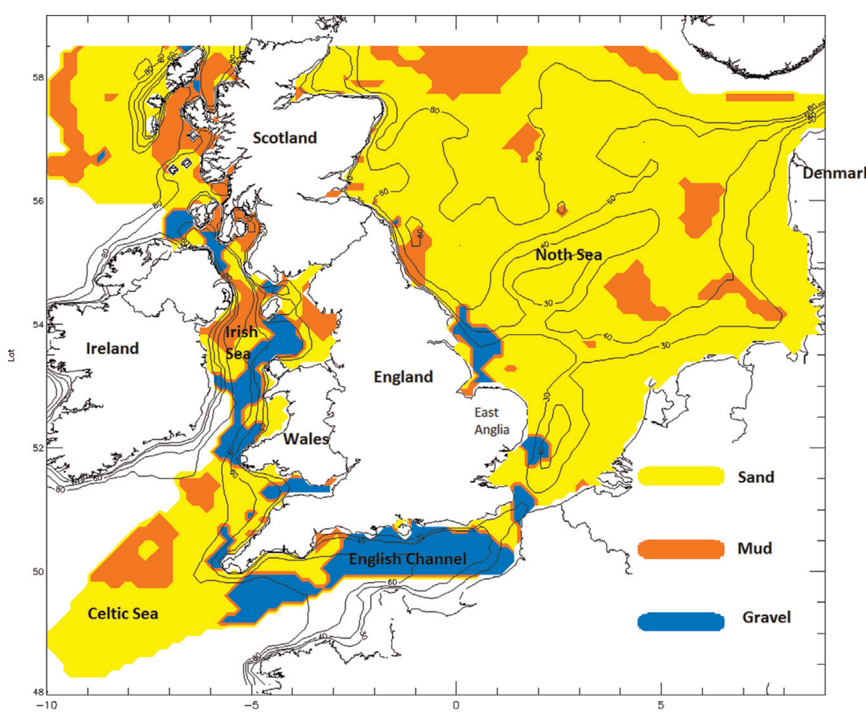

Fig. 1. Bathymetry and bed substrate distribution used in this study. Bed substrate data from North Sea benthos Survey, The British Geological Survey and Cefas. Blank sea areas indicate no bed sediment data.

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