ECOWind-ACCELERATE: accelerated seabed mobility around offshore windfarms.

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ABSTRACT: To identify opportunities for wider conservation with stackable benefits around offshore windfarms (OWF), we need to quantify existing changes and predict future changes to the marine environment from OWF expansion, with trophic interactions that start at the seabed. We are therefore building a calibrated and validated high-resolution local area coupled flow-sediment transport model to quantify the impact of OWF modified flows on seabed mobility (sediment transport, seabed composition and morphology). This will then be combined with impacts on the seabed from climate change. Here we focus on using various sizes of OWF and representing realistic seabed sediment composition, and preliminary results from flume laboratory experiments and TELEMAC 3D modelling will be presented at the MARID conference. This work is part of the new ECOWind-ACCELERATE project, where the team will quantify the impact of the seabed modifications on seabed habitats and the knock-on consequences for epi-benthic fish distribution and deep-diving seabirds.

1 INTRODUCTION

Offshore windfarms will be developed at an accelerated schedule under fast-track plans to switch away from fossil fuels. With ever larger offshore windfarms, and the cumulative effects of climate change, we thus urgently need to understand the way the seabed is modified in response and how such changes affect the wider marine ecosystem.

1.1 Seabed mobility around seabed infrastructure.

The seabed infrastructure associated with OWFs includes turbines, foundations and cables, plus the protective materials to keep it all safe. When natural currents in the water column deviate around such objects, the forces acting on the seabed enhance by up to a factor of four, with impacts stretching several kilometres beyond the object (Smyth and Quinn 2014, Whitehouse 1998, Vanhellemont & Ruddick 2014). These changes modify the properties and mobility regimes of the seabed, particularly at shallow cable corridor sites. It has been suggested that the effects that relate to the growing size of OWFs may be felt regionally, rather than just locally (van Berkel et al., 2020).

1.2 Seabed mobility driving habitats.

Habitat maps and models, which underpin local to regional marine spatial management via valuations of ecosystem services (ES), rarely consider dynamic changes to the seabed. Changes in substrate and suspended sediment load can define habitats, across a range of spatial scales, including: (i) changing extent and distribution of habitats (e.g. Fig. 1 – see end of this document); (ii) changing structure and function of habitats; and (iii) changes in supporting processes such as sediment suspension on which habitats rely. The close association of habitat type with the identity and diversity of benthic fauna mean such changes in habitat are likely to have significant impacts. For example, the coarsening of habitat and introduction of hard substrates is likely to enhance species richness, abundance and productivity (Benoist et al 2019). On sand banks, even subtle changes in the proportion of silt drives changes in important high-calorie epi-benthic prey for deep-diving predators (Wright et al., 2000; Langton et al., 2021).

1.3 The mixed nature of seabed sediments in the Eastern Irish Sea.

To assess the impact of OWFs anywhere around the UK, an in-depth study is required across a range of depths, seabed habitats and OWF sizes. The Eastern Irish Sea is the ideal test bed for accelerated ecosystem impacts from OWF expansion. This area hosts several existing OWFs and four large planned OWFs (Fig. 1) lie within 10-20km of each other, and of other sites (incl. planned carbon storage). The variable seabed (Fig. 1-C1) defines habitat suitability (Fig. 1-C2), and the sand banks amid coarse sediments represent many environments also found in the S North Sea (Fig. 1-A).

1.4 Problems with predicting seabed mobility.

Uncertainty in sediment transport models is greater when the seabed is mixed, and with seabed composition as an important driver of habitat suitability (Fig. 1), benthic habitat maps are only relevant when the changing state of the seabed is considered. Mixed beds can experience energetic conditions just under the threshold of motion for the sand fraction, modified by the presence of gravel (McCarron et al., 2019). Any flow amplification could dislodge this sand and even form mobile sand waves. These could amplify the flow further and sand wave trains can extend many kilometres in the far-field of the original obstruction (see Section 2).

1.5 Physical modelling and field observations to validate/calibrate sediment transport.

Real-world observations (see Section 2) and scaled physical experiments (see Section 3) of flow modification can be used to calibrate and validate modelled predictions of local hydrodynamic modifications and seabed sediment transport. We recently validated TELEMAC-SISYPHE model outputs against observed flow deviations around individual objects, such as the SS Apapa shipwreck to the north of Anglesey, North Wales, UK (Fig. 2), with 18 repeat seafloor surveys since 2012. Larger scale effects will be assessed during the new ECOWind-ACCELERATE project.

1.6 Aims of this work.

No field-scale data exist yet from the much larger planned OWFs, to determine their cumulative impact from the increased “fetch”. We will thus use the world-class laboratory of HR Wallingford to run experiments to investigate the impacts of different OWF array scales on sediment transport, using existing length scale approaches (Frostick et al 2011) to ensure geometric similarity between experiments, offshore data and the hydro-morphodynamic model, with a best practice scaling approach (Whitehouse 1998). The main questions we focussed on:

- How well do the predicted hydrodynamics (using a sub-grid scale representation of a monopile or monopile array) represent actual effects on flow velocities?
- How does monopile diameter affect wake properties (i.e., downstream and cross-stream flow velocity anomalies)?
- How will increasing monopile diameter affect flows and bed morphodynamics?

2 OFFSHORE DATA AS INSPIRATION

2.1 Seabed mobility due to flow diversion around objects.

The team has been monitoring change in seabed mobility around seabed objects on mixed and coarse beds, as this is where many Offshore Wind Farms (OWF) around the UK will be built. Flow diversions around OWF objects and sedimentary bedforms are responsible for additional energy in the water column and for winnowing of the sand fraction with subsequent generation of migrating sand waves inducing further sand winnowing. This can result in mobile sands many kilometres beyond the initial flow diversion, even at depths of 50-80m (Fig. 2-A, B1), and these can host different benthic communities (Cheng et al., 2021). A small disintegration of the SS Apapa wreck resulted in a demonstrable shift in seabed mobility regime (Fig. 2-B2) with lateral changes in seabed composition over 100s of metres, new scour pits and a reversal in the migration direction by a 2.5m high sediment wave.

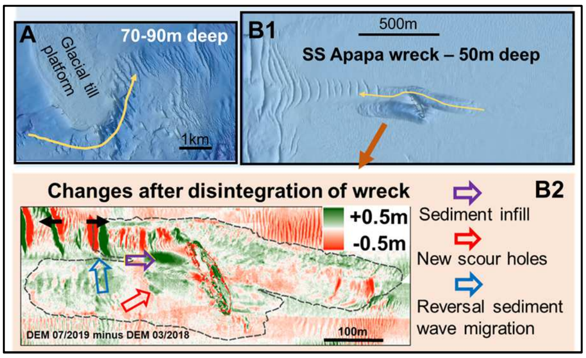

Figure 2. Seabed observations to capture impact of accelerated flow on bed mobility: Flow diversion causes sediment wave trains to form around glacial till platform (A) and a shipwreck (B).

2.2 Enhanced turbulent kinetic energy in the wake of a large sediment wave.

In the summer of 2021, our Bangor University team deployed an upward-facing ADCP on a frame near a 15m high sediment wave (Fig. 3). There is quadrupling of turbulent kinetic energy (TKE) 200m away from this large sediment wave (Fig. 3). The increase in TKE which persists up to 35m above the bed.

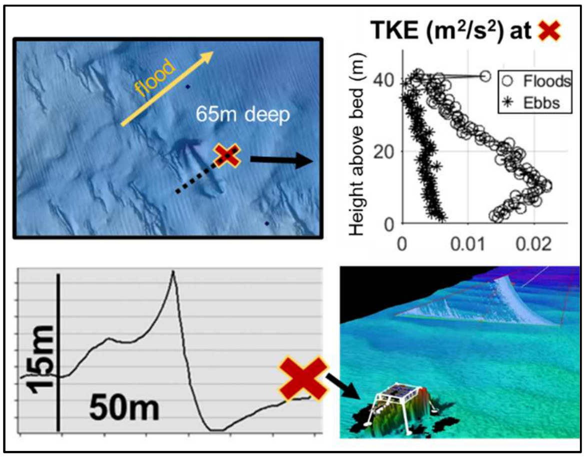

Figure 3. Seabed observations to capture impact of accelerated flow on bed mobility: Enhanced TKE in the wake of a 15m high sediment wave.

2.3 Seabed changes in the wake of a wind turbine.

From SEACAMS data around the scour-protected monopiles of the Rhyl Flats OWF, there are also signs of increased seabed mobility (Fig. 4) and changes to sedimentary bedform dimensions. The monopiles are nearly a third of the size of the monopiles we will see in future installations. The effect of flow diversion has altered the seabed from an exposed glacial bed of sand and gravel to a sandy bed with sediment waves in the wake of the turbine (Fig. 4 – bottom image). The reversed process can also happen, where the sediment waves already existed, but they have been washed away in the wake of the turbine (Fig. 4 – top image). These effects can extend for more than 100 times the diameter of the monopile, and where sediment waves are generated, they often set off a train of sandy bedforms for many more kilometres.

The way heterogeneous beds of glacial tills supports ecosystems will differ from the way a clean sandy bed does. So the impacts are profound and the impacts are variable, and the ECOWind-ACCELERATE project aims to predict this.

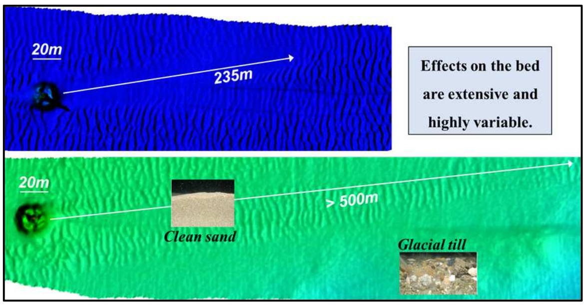

Figure 4: Increased seabed mobility by monopiles of the Rhyl Flats OWF in the Eastern Irish Sea. The seabed images are hypothetical.

2.4 Many different seabed substrates.

The Irish Sea was the scene of a massive ice stream draining the British-Irish Ice Sheet (Clark et al., 2022). This left behind sediments of all sizes and consolidation, and in the Irish Sea, there is great spatial variability in seabed sediment type (e.g. Fig 1 and example seabed images in Fig. 5). Having these gradients of different seabed substrates will allows us to use the spatial variability of today's relationships between bed and habitats to predict the future use of habitats.

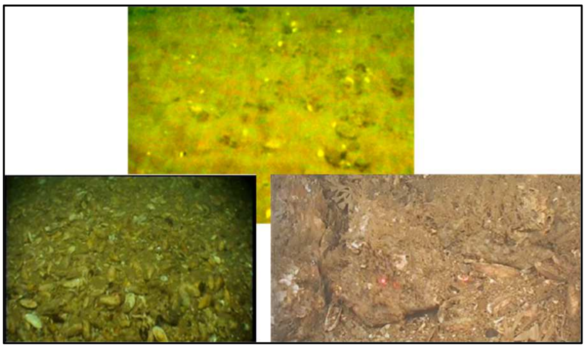

Figure 5: Images from the variable seabed in the Irish Sea (Van Landeghem, 2008).

3 EXPERIMENTAL FLUME LAB SETUP

3.1 Wave-current-sediment basin.

The UK Coastal Research Facility at HR Wallingford is a 27m wide by 54m long wave-current-sediment basin. Within the basin, a flume with working area of 3m wide by 30 m long was built. With an operational depth up to 0.8m, discharge is less than 1.2 m^3/s.

3.2 Instruments.

Hydrodynamics will be monitored using a vertical array of acoustic Doppler velocimeters (ADVs) and a Vectrino Profiler. These velocimeters will provide flow information at:

- 80% of flow depth (Top): Sideways looking ADV.
- 60% and 40% of flow depth: downwards looking ADV.
- 20% to bed: Vectrino Profiler.

Measurements will be taken across a 2D grid of points surrounding the monopile. Footage of the water surface will also be recorded using a high frame rate camera positioned directly above the monopile. Surface flow information will be obtained from PIV analysis of footage to support the vertical flow information.

Bed morphodynamics will be assessed using pre- and post-experiment bed scans collected using a 2D laser bed scanner.

3.3 Experimental design and integration with numerical models and offshore data.

The experimental setups includes cases with a single turbine, with a diameter that represents existing developments (e.g. monopiles of 5m in diameter) and a future Round 4 larger style monopile (12m diameter). Flow measurements and their morphodynamic extent will be measured offshore in the summer of 2023 in the wake of OWF. The TELEMAC-SISYPHE model will be configured to emulate the physical modelling setup, cross checked in both 3D and 2D mode.

Due to a slight delay in the work schedule, we cannot present preliminary results of the flume laboratory experiments in this extended abstract, but they will be presented at the MARID conference.

4 CONCLUSIONS

The forces acting on the seabed are guaranteed to change more rapidly over the next few decades due to accelerated effects of the climate crisis, interacting with the combined accelerated flows around new large OWF infrastructure. These have the potential to change seabed mobility regimes, thus inducing changes to the integrity of the seabed, its habitats and associated benthic biodiversity and ecosystem services (both positive and negative).

Our outputs will provide valuable information not only for determining the rates and loci of seabed change for benthic habitat assessments, but also for the future design of resilient OWFs and inter-array and export cables that are vulnerable to the impacts of seabed currents, waves and human activities such as fishing. We thus aim to inform decision making by project partners on designing future climate change-adaptive and resilient structures.

5 ACKNOWLEDGEMENT

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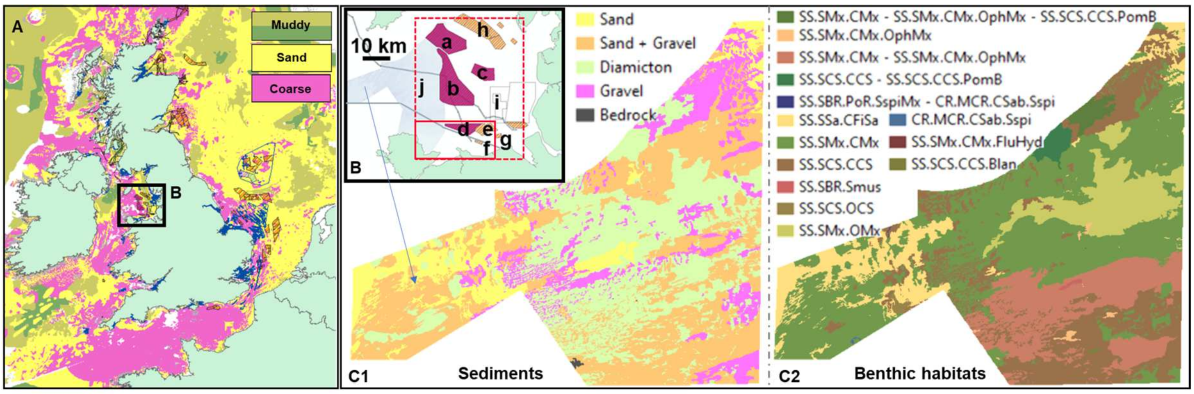

Fig. 1: A: About 24% of UK seabed has mixed and coarse sediments: many where windfarms are in place or planned (dashed polygons) and with sand banks (in blue) where sand is winnowed out. Data extracted from EMODnet – Sept 2021 version. B: Eastern Irish Sea, with OWFs Mona (a), Morgan (b) and Morecambe (c), within 10-20 km from the planned OWF Awel-y-Môr (d), the existing OWF Gwynt-y-Môr (e), Rhyl Flats (f), North Hoyle (g), Walney sites (h), and from a planned carbon storage site (i). Cable instalments for which we have data in grey, and two modelling domains of high-resolution bed stress modelling in red. C1-2: The Rhiannon dataset (j in (B)), has seabed sediment types (C1) defining benthic habitat distribution (C2).