# Sediment transport pattern of two nearshore sandbanks inferred from time-lapse surveying of sand dunes

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## Abstract
Morphodynamic of sand dunes associated with two separate nearshore sandbanks lying in the Bristol Channel, is described and quantified to investigate the sedimentary processes maintaining these banks connected to the shore. Migration of sand dunes and estimation of sediment transport rate are interpreted from repeated multibeam and singlebeam bathymetric data. Sand dunes associated with the Helwick bank (western Swansea Bay) migrate in opposite direction on each side of the bank at a speed ranging from $6.9 \times 10^{-8}$ $m.s^{-1}$ (0.001 $m.d^{-1}$) to $3.46 \times 10^{-6}$ $m.s^{-1}$ (0.3 $m.d^{-1}$) but strangely appear to connect over the crest of the bank. Total sediment transport is estimated within the range of $1.16 \times 10^{-7}$ to $7.18 \times 10^{-6}$ $kg.m^{-1}.s^{-1}$ (0.01 to 0.62 $kg.m^{-1}.d^{-1}$). The Nash Sandbank (eastern Swansea Bay) shows migration values between $2.31 \times 10^{-8}$ to $8.8 \times 10^{-6}$ $m.s^{-1}$ (0.002 to 0.76 $m.d^{-1}$), implying sediment fluxes ranging between $3.47 \times 10^{-7}$ to $1.37 \times 10^{-5}$ $kg.m^{-1}.s^{-1}$ (0.03 to 1.18 $kg.m^{-1}.d^{-1}$). The maximum rates are observed for transient bedforms (time life of at least 19 days).

## 1. Introduction
Tidal headland-connected sandbanks are linear sand bodies found in tidal estuaries. Their origins and maintenance have been suggested to be explained by the generation of eddies (O(1km)) in the residual currents, originating from the acute change of direction of the shore (Pingree and Maddock, 1979 Pattiaratchi and Collins, 1987). However, little effort has been given to the sedimentary processes affecting the immediate connection of the bank with the coast where currents have been reported to be highly variable in direction and strength (Geyer and Signell, 1990). The aim of this paper is to describe and quantify the characteristics of sediment transport of two sandbanks at the immediate vicinity with their connection with the shore, from the morphodynamics of associated sand dunes.
The Helwick is a linear sandbank lying in the outer Bristol Channel, west of Swansea Bay. The Nash sandbank lies in the inner Bristol Channel, further east than Swansea Bay. Both banks are affected by macro-tidal flows and significant oceanic wave energy originating from the Atlantic and the Irish Sea. Both banks host bedforms ranging from dunes to ripples at their connection with their respective headlands.

## 2. Methods
Repeated surveys have been undertaken over these banks with a Reson 8101 (240 kHz) multibeam sonar and an Odom hydrotrack (200kHz) singlebeam echo-sounder. Positioning accuracy for both types of surveys is estimated to be around 1m. Table 1 gives a summary of the different surveys, their location, and the period between them (see location on figure 1 and figure 2).
Dune migration was measured from the displacement of individual sandwave between the surveys. Tracking of the dunes is supported by morphological similarities between the survey, both in plan and profile views. Migration was measured at the centre of the dunes (defined as the centre of a triangular shape composed of two successive troughs and a crest). Sediment transport rate was estimated with the following formula:

$$q = \frac{1}{2}.C.H.(1-p).d$$

This equation, based on conservation of mass and kinetic equation for the propagation of bedforms, relates specific sediment transport rate (q in $kg.m^{-1}.s^{-1}$) with dune migration rate (C in $m.s^{-1}$), dune height (H in m), porosity (p fixed at 40% for an averaged mixed and averaged packed sand (Terzaghi and Peck,1967)) and density of quartz (d = 2650 $kg.m^{-3}$).

| Date | Time delay | Type of survey | Geographic extent |
|---|---|---|---|
| September 2001 | 0 | Multibeam | ***Helwick***: Port Eynon Bay – Eastern Helwick (north flank and south flank) |
| August 2002 | +328 days | Multibeam | ***Helwick***: Port Eynon Bay – Eastern Helwick (north flank and south flank) – towards Worms Head |
| May 2003 | +278 days | Singlebeam | ***Helwick*****:** Eastern Helwick (2 lines from Port Eynon Point along the southern flank, 5 lines from Port Eynon Point along the northern flank, 3 lines along the coast from Port Eynon Point to Worms Head) |
| August 2002 | 0 | Multibeam | ***Nash***: Eastern Nash, northern and southern flanks, along the coast. |
| September 2002 | +19 days | Multibeam | ***Nash***: Eastern Nash northern and southern flanks and southern flank of mid Nash |
| May 2003 | +219 days | Singlebeam | ***Nash***: 8 lines along the coast (Nash Point Trwyn-y-Witch), 5 lines on the northern flank, 6 lines along the southern flank, 6 lines between the bank and the coast at the connection of the bank with the shore |

**Table 1 Repeated bathymetric surveys over the Helwick Sandbank and the Nash Sandbank**

## 3. Results

Fluxes of specific sediment transport are reported on figure 1 and 2 respectively for the Helwick and the Nash. Both figures are composed of an underlying grey shaded relief of the high resolution bathymetry showing the seabed morphology. For both bank, a description of the seabed morphology will be followed by some results concerning the migration of the dunes, before finally commenting on the fluxes of sediment transport.

### 3.1. The Helwick

The multibeam survey (fig. 1) highlights Port Eynon point bedrock, from which Helwick sandbank extends. The sandbank top lies between ~13 m below chart datum, directly west of the Port Eynon Point and ~5 m further west. In the area of interest the northern flank of the bank has a ~0.5° gentle slope whereas the southern flank dips with a ~3° angle. The northern and southern flanks are covered with sand dunes. These dunes have a typical height of ~4 m and a wavelength of 100-200 m. They generally tend to be asymmetric with rounded crest ("cat back" to "progressive" morphology according to Dyer's classification (Dyer 1986)). However, near the eastern corner of the dune field, near the main headland, and close to the crest of the bank they adopt a trochoidal profile, slightly asymmetric form. Dune crests are generally perpendicular to the crest of the bank but tend to become parallel to the crest of the bank as they traverse its flanks. Despite opposite asymmetry on both flanks of the bank, they tend to connect over the crest of the bank which constitutes an atypical and yet unexplained behaviour for these sand dunes.

Displacement of the dunes is generally parallel to the crest of the bank, in an east-west direction. On the northern flank the migration is towards the east ranging from $8.1\times10^{-7}$ to $2.31\times10^{-6}$ $m.s^{-1}$ (0.07 $m.d^{-1}$ to 0.2 $m.d^{-1}$) with increasing water depth. On the southern flank migration rates are of the order of $2.31\times10^{-6}$ $m.s^{-1}$ (0.2 $m.d^{-1}$). Orientation, direction and intensity of total sediment transport are reported on figure 1. On the northern flank it varies from $1.16\times10^{-7}$ to $6.94\times10^{-6}$ $kg.m^{-1}.s^{-1}$ (0.01 to 0.6 $kg.m^{-1}.d^{-1}$). Highest values of the flux are located in the middle of the slope, where dune height is fully developed. As a comparison the flux is estimated at $1.16\times10^{-1}$ $kg.m^{-1}.s^{-1}$ (0.1 $kg.m^{-1}.d^{-1}$) at the crest of the bank, where waves orbital velocity is known to induce shear stress at low tide. Opposite direction of the flux, with typical intensity of $3.47\times10^{-6}$ to $4.63\times10^{-6}$ $kg.m^{-1}.s^{-1}$ (0.3 to 0.4 $kg.m^{-1}.d^{-1}$) is observed on the southern flank.

### 3.2. The Nash

The multibeam survey data collected in 2002 shows the morphologic features around Nash Bank (fig. 2). The eastern part of the bank connects to the shore at Nash Point headland. The bank has a width of ~1km. Most of this width is occupied by a platform which dries at the lowest astronomical tides. The transition between the crest and the southern flank is characterised by a steep slope (more than 10°) whereas, on the north flank, the slope is gentle (less than 1°). In the immediate vicinity of the bank, on its northern flank, 2.5m high dunes show an asymmetrical progressive morphology with their lee face facing east. On the southern flank they show a "cat-back" morphology with a lee face facing west. Along the coast, in the north-west part of the survey, a field of dunes (up to 3m high), presenting their lee faces towards the northwest suggests a long-shore driven sediment transport towards Swansea Bay. Finally, in the area between the eastern sandbank and Nash Point, known as Nash Passage, transient sandwaves have their lee faces oriented towards southeast, whereas in the north-west extremity of the dune field their lee sides are north-western facing.

On the northern flank, migration rates of the sand dune towards the southwest range from $1.16 m.s^{-1}$ to $6.94x10^{-6}$ $m.s^{-1}$ (0.1 to 0.6 $m.d^{-1}$). An opposite direction is observed on the southern flank with a similar rate ($6.94x10^{-6}$ to $9.14x10^{-6}$ $m.s^{-1}$). Short term (19 days) and long term (219 days) migration rates are in agreement. The dune field located at the Nash Passage (connection with the shore) shows two groups of migration direction, as suggested from the description of the morphology. The south-eastern group migrates south eastward at a speed ranging from $1.16x10^{-6}$ up to $2.2x10^{-5}$ $m.s^{-1}$ (0.1 to $1.9 m.d^{-1}$) as water depth decreases. It is believed that the funnelling effect of the tide between the bank and the coast at this location is responsible for such fast migration rates and the transient nature of the bedforms (it has not been possible to match the dunes here over the longer term comparison). A smaller north west group migrates north westward at smaller rate ($3.47x10^{-7}$ to $3.47x10^{-6}$ $m.d^{-1}$). Finally, a group of migrating dunes is observed along the coast on the northern part of the survey. Average displacement is towards the north west at speed ranging from $1.16x10^{-7}$ to $1.16x10^{-6}$ $m.s^{-1}$ (0.01to $0.1 m.d^{-1}$), with migration rates generally decreasing with water depth.

The general scheme of orientation, direction and intensity of the migrating bedforms is shown on figure 2, displaying the orientation, direction and intensity of the total sediment transport. Flux of sediment observed on both side of the bank, suggest an equilibrium of the sediment transport on the northern flank (0.1 $kg.m^{-1}.d^{-1}$ to 0.4 $kg.m^{-1}.d^{-1}$) with the southern flank ($1.16x10^{-6}$ to $6.9x10^{-6}$ $kg.m^{-1}.s^{-1}$). Meanwhile high sediment transport rate are observed at the connection of the bank with the shore reaching $1.62x10^{-5}$ $kg.m^{-1}.s^{-1}$ (1.4 $kg.m^{-1}.d^{-1}$), directly related to the high migration rates mentioned previously.

## 4. Discussion and conclusion

Specific sediment transport was estimated from migrating sand dunes associated with the Helwick Sandbank and the Nash Sandbank, at their connections with the coast. These results suggest that both banks are in equilibrium within the uncertainty of the technique employed. However specific behaviour of the associated bedform at the immediate vicinity of their connection with the shore suggests specific mechanism of sediment transport for each bank resulting from different hydrodynamic forcing. At the Nash Sandbank, on one hand, transient and rapidly migrating sand dunes were observed where the current is funnelling between the headland and the bank's crest. On the other hand, at the Helwick Sandbank, sand dunes connect over the crest of the bank despite opposite migration and sediment transport but relatively similar intensity. One suggestion which might explain such an atypical behaviour is to consider lateral sediment transport parallel to the axis of the dunes such as described by McCave and Langhorne (1982).

Morphological similarity of the dunes between the surveys suggests that sediment transport is mostly occurring as bedload. However, suspended load is believed also to have a role for at least two reasons. First, both of the banks are submitted to significant waves energy originating from the Atlantic. Secondly, flow separation over dunes is known to occur from the crest to the reattachment point on the next stoss slope, restricting the bedload on the upper part of the dunes (Bennett and Best, 1995). Therefore there will be a continuous exchange between suspended and bedload transported particles. Part of this exchange is believed to be taking place by means of smaller bedforms, such as ripples and megaripples, developed on the stoss side of some of the major dunes on both banks. Whitehouse (2000) suggests that the volume of sand transported by these bedforms can be a significant proportion of the sand transported across dunes. However, assessing this volume would be difficult with the present technique.

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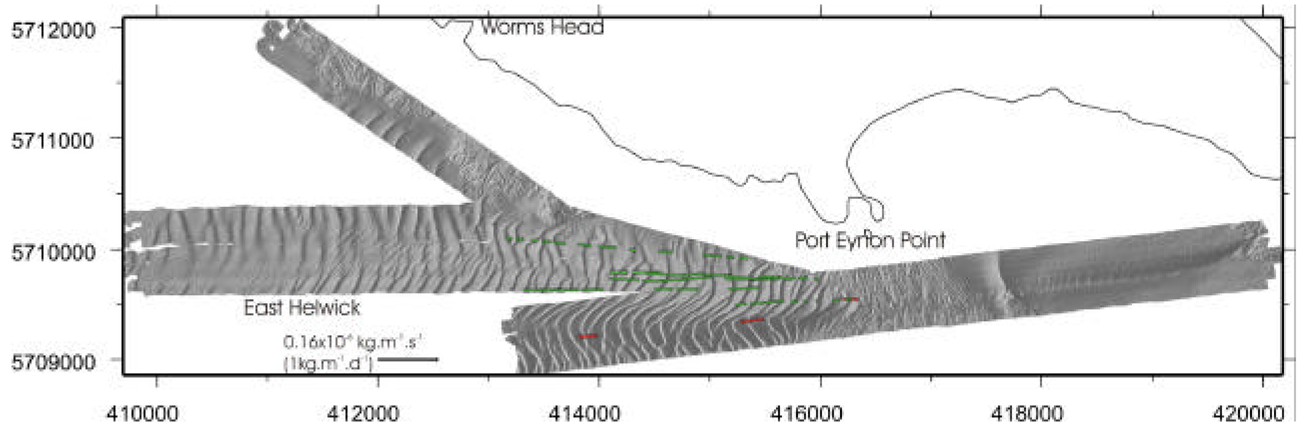


**Figure 1 Determined sand transport vectors around the Helwick sandbank at the connection with the shore (red: 2001 to 2002; green 2002 to 2003). Underlying shaded relief bathymetry from the 2002 multibeam survey. The illumination is from the West. Coordinates are in UTM.**

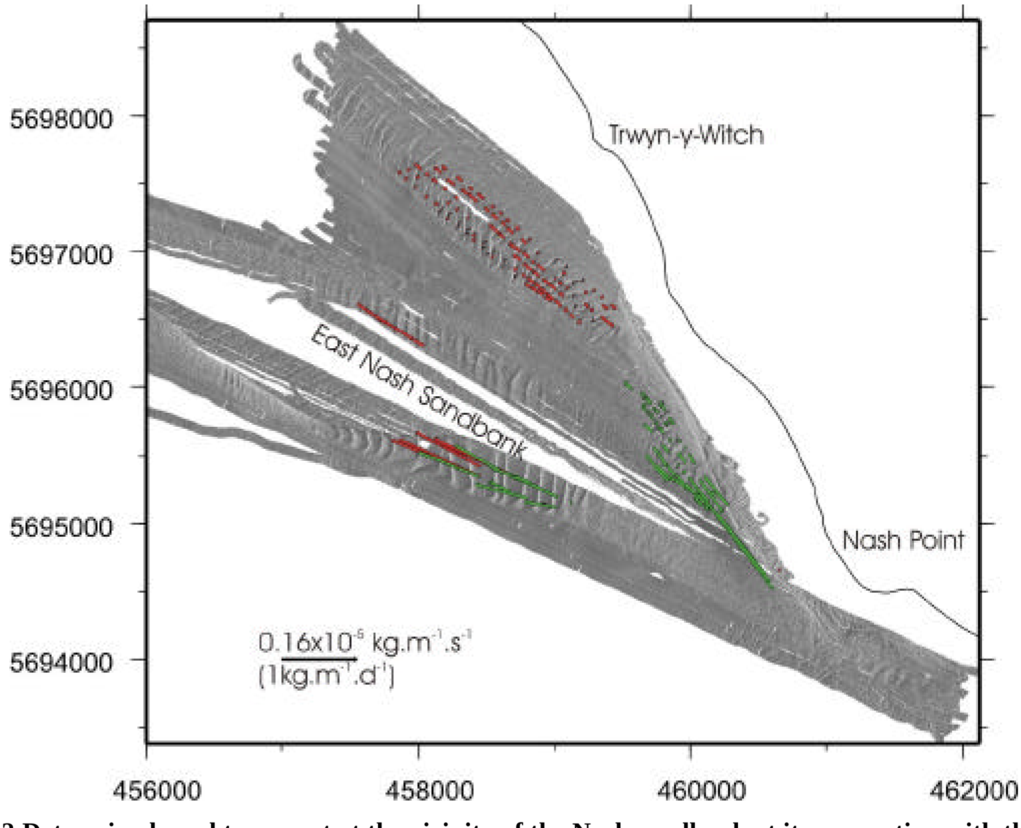


**Figure 2 Determined sand transport at the vicinity of the Nash sandbank at its connection with the shore (red long term comparison between 2001 and 2002; green: short term 19 days apart in 2002). Underlying shaded relief from the 2002 multibeam survey. Sun illumination is from the west. Coordinates are in UTM.**