Dune migration around a bar within a tidal system

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ABSTRACT: Sediment transport processes within river-estuary systems are governed by the complex interplay between tidal and fluvial hydrodynamics, resulting in a poorly defined transition zone between fully tidal and fully fluvial bedforms. This paper investigates the morphodynamics of large scale bedforms around a large bar within a braided tidal-fluvial transition zone. The migration and adjustment of the bedforms to local flow patterns are investigated using multibeam echosounder (MBES) bathymetric surveys and acoustic Doppler current profiler (ADCP) flow measurements. Bedforms are observed on multiple scales, with the largest found to be fluvially-dominated, and steered around the barhead. Smaller superimposed bedforms exhibit a tidally-derived morphology, notably in seaward regions of the bar. Results also show that migration of the larger bedforms, whilst appearing fluvial in terms of their morphology, are actually dynamically linked to the tidal flows with some upstream migration. This has implications for our understanding of the process mechanics of bedforms in this complex region.

1. INTRODUCTION

The combined tidal and fluvial inputs to river-estuary systems result in a complex landward transition from tidally-dominated zones through to tidally-influenced river systems. This transition is highly mobile, depending on local tides and fluvial flows, moving on daily, monthly and seasonal cycles. The maximum upstream incursion of the tide, known as the tidal maximum, occurs within the fluvially-dominated region of the river-estuarine system, at which point the fluvial currents are only slowed and modulated by high tides. Closer to the ocean, tidal influence increases and fluvial flow will stop or can be reversed (Dalrymple and Choi, 2007). At a given time, the position of the tidal limit will vary dependent on local river levels, tidal range and estuary geometry (Dalrymple et al., 1992).

The resultant flows and sediment transport processes, whilst sharing characteristics, will reflect the environment in which they formed (e.g., Best et al., 2003; Bridge, 1993; Fustic et al., 2012; Martinius and Gowland, 2010). Sediment transport will vary through this region as the fluvial flow is modulated or reversed (Dalrymple and Choi, 2007; Dalrymple et al., 2012). Whilst distinct patterns of bedforms may be observed from fully-tidal to fully-fluvial, the resultant bedforms may be modified or have a variable morphology due to the movement of the tidal-fluvial transition.

This paper investigates the bedforms found in a fluvially-dominated estuary system and their accommodation to local flow conditions and topographic forcing. The effects of the tidal-fluvial interaction on the resultant bedforms and their migration will be investigated.

2. FIELDSITE

The Columbia River is the largest river on the Pacific coast of North America, with a drainage basin of 660, 480 km^2, entering the Pacific Ocean near to Astoria, Oregon, US (Gelfenbaum, 1983; Simenstad et al., 2011). A meso-tidal system, the turbidity maximum is highly mobile in response to variations in river flow and tides, moving by up to

20 km (Gelfenbaum, 1983). The estuary is predominantly sand-bedded, with the rate of bedload transport varying with river flow (Jay et al., 1990). The area studied is near Astoria, OR about 40 km upstream from the mouth of the estuary (Jay et al., 2011). This region is fluvially-dominated and contains significant bar complexes with two primary channels, a regularly dredged navigation channel which is the main shipping route and a second deep channel to the south (Figure 1). The present work investigates the bathymetry and flow around a single bar in the landward region of the Columbia River Estuary, located within the secondary channel (Figure 1).

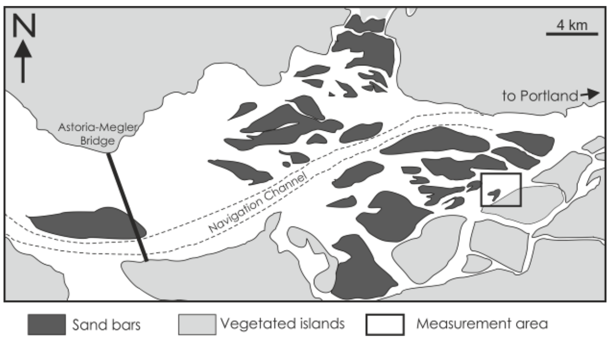

Figure 1. The Columbia River Estuary, WA, USA. Well -developed bar complexes can be seen throughout the estuary, some of which are vegetated. The bar investigated herein is located within the landward region of the bar complex, adjacent to the secondary deeper channel.

3. METHODOLOGY

Bathymetric measurements were made using a Multibeam Echosounder (MBES) of a region 1.9 km by 1 km surrounding a large bar which became fully submerged at high tides. This bar is situated within the braided region of Cathlamet Bay at the landward end of the estuary and is 950 m in length and 400 m wide (Figure 2). The measured section mainly consists of a shallowing sand bar with surrounding bifurcated channels. Flow measurements were also made using an acoustic Doppler current profiler (ADCP) along several transects around the bar at different tidal-fluvial conditions to investigate the local fluid flow structure through the evolving tidal conditions.

4. RESULTS

Bathymetry measurements were made as close to the bar top as the equipment allowed. The shallowest regions measured, on the bar top, are 1.1 m deep relative to local mean sea level, with small scale dunes, which increase to a 2 m wavelength in slightly deeper regions. The edge of the bar is marked by deeper channels containing larger scale bedforms. The southeastern edge of the measured section contains channel 9.5 m deep relative to local mean sea level, with sinuous dunes up to 4m in wavelength, oriented in a seaward direction. The northwestern margin contains a wider channel 7 m deep, with large dunes 40 m in wavelength and relative crest heights of 0.9 m.
The region landward of the barhead contains several northeast – southwest oriented longitudinal dune crests with crest separations of up to 200 m and crest heights of approximately 1.5 m. Cross cutting these dunes are large sinuous dunes with a northwest – southeast orientation, with crest lines continuing across the longitudinal dune margins. These dunes are approximately 40 m in wavelength with relative crest heights of 0.9 m; again, superimposed on the dunes crests are smaller dunes.

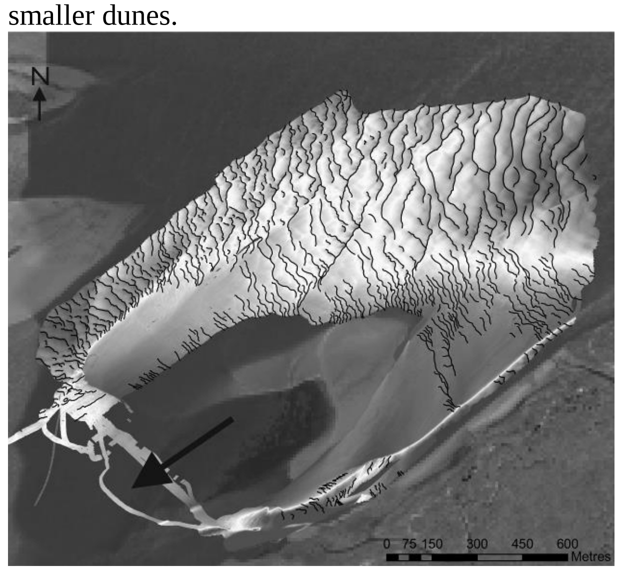

Figure 2. Multibeam echosounder bathymetry of the bar investigated herein (location shown in Figure 1). The variation in crest orientation (marked in figure) can be clearly seen the largest of which form longitudinal crests oriented north-east southwest, oblique to the dominant flow direction (shown as an arrow). Smaller bedforms are oriented with the dominant flow.

The longitudinal dune features have formed with crests oblique to the local flow patterns and matches the orientation of dunes further landward within the same channel. The cross-cutting smaller dune crests are oriented with the local flow, showing the adaptation of sediment transport to the local topographic conditions. Modification of sediment re-routing structures by the incoming flood tide is observed close to dune crests.

Smaller bedforms (< 2 m in wavelength) are superimposed on the larger dune crests across the entire domain, with crest orientations matching the larger bedforms. Whilst those observed in the shallower bar adjacent regions have a more symmetrical, tidally-influenced geometry, the superimposed bedforms are more fluvially-dominated.

Migration of bedforms at all scales can be observed in repeated measurements made across several days. Some landward migration is observed, although the morphology of the bedforms remains strongly fluvial in nature.

5. CONCLUSIONS

Within a tidal system, detailed bathymetric and flow measurements around a large bar reveal fluvially-dominated bedforms. These bedforms occur at a number of scales and show rapid migration and adjustment to flow around the local topography. Although the bedforms appear to be fluvial in character, their migration is also influenced by the incoming tides. This cryptic nature may result in the misinterpretation of similar bedforms as fully fluvial, missing the tidal nature of the system.

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