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Long-term evolution of a sand spit, physical forcing and links to coastal flooding

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A B S T R A C T

Aerial photographs, topographic field data and environmental forcing agents were used to assess historic and annual sand spit changes at Ginst Spit, Pendine Sands, West Wales. Aerial photographs highlighted that the spit shoreline facing the dominant wave direction had accreted steadily throughout the assessment timeframe (1947–2010). Stabilisation works in the form of rubble mounds aided recovery of the dune system thought to have been damaged due to training exercises carried out during the Second World War. Annual topographic surveys (1995–2010) showed a terminal end eastward migration extending into the channel of the 3 estuary complex. Dominant waves emanate from south southwest, and wave models suggest that longshore sediment drift is from west toward east. Sub-dominant southeast waves create a counter drift back toward the west forming the customary northward hook. Model results showed significant wave transformation from offshore model boundaries to the nearshore zone for both wave height and direction, which found agreement with qualitative assessment. Annually averaged wave components showed varying correlations with sand spit rates of shoreline change. Precipitation and spit growth were associated with flood events, which suggested that a combination of fluvial and coastal processes contribute to lowland inundation. By showing the major role the spit plays in protecting the town in its lee, this work provides a new understanding of sand spit evolution to inform coastal management.

Introduction

A spit is a ridge or embankment of sediments attached to land at one end, with the other ending in open waters and being younger than the land to which it is attached (Teodoro, Pais-Barbosa, Gonçalves, Veloso-Gomes, & Taveira-Pinto, 2011). They evolve through formation of a submarine feature, which is a shallow sloping sand surface extending from low water to a depth of several metres (Davis & Fitzgerald, 2005, p. 385). Morales, Borrego, Jiminez, Monterde, and Gil (2001) found that a spit-platform downdrift of a barrier spit followed a cyclic pattern of downdrift migration and breaching. According to Vinther, Aagaard, and Nielsen (2005), spit-platforms define this feature have received little attention in the literature, despite their expected importance for understanding sediment transport mechanisms leading to tidal channel siltation.

The topographic boundary of a sand spit is not well-defined, because the boundary is not static in time, unlike the majority of water bodies (Teodoro et al., 2011). The use of image classification tools, specifically image classification algorithms, reduces time and facilitates more accurate identification of morphological and hydrodynamic features/patterns, and consequently sand spit boundary extraction (Teodoro, Pais-Barbosa, Veloso-Gomes, & Taveira-Pinto, 2009). Long-term shoreline morphological changes are often estimated using aerial photographs, and to lesser extent historical maps in conjunction with various forms of topographic surveying techniques (Sorensen, 2006, p. 319; Zhang, Huang, Douglas, & Leatherman, 2002). It is critical that any uncertainty in shoreline position is properly accounted for, in order to statistically test coastline change signals (Ruggiero, Kaminsky, & Gelfenbawn, 2003). This uncertainty depends on the accuracy and precision of survey measurements together with stability of shoreline position indicators (Douglas & Crowell, 2000), and the choice of a suitable shoreline change indicator is a fundamental consideration of all coastline mapping. In this environment, an ideal position indicator would be easily identified both on site and all aerial photographs (Leatherman, 2003; Parker, 2003; Zhang

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et al., 2002). The shoreline definition for coastal research is often taken to be the mean high water level (MHWL; Simm, Brampton, Beech, & Brooke, 1996, p. 448; Zhang et al., 2002), but alternatively, the vegetation line can be used (Morton, 1991). Thomas, Phillips, and Williams (2010) and Thomas, Phillips, Williams and Jenkins (2011) used the vegetation line when mapping shoreline changes at Tenby, South West Wales, as they found that MHWL in a macrotidal environment was difficult to observe. Nevertheless, they were able to map historic beach rotation that was subsequently linked to nearshore changes and to sand spit destruction. Ashton, Murry, and Arnault (2001) showed that when the incident angle of deep water waves to the main shoreline exceeds 45°, shoreline instability occurs, which can result in development of a sand spit from a small shoreline perturbation. According to Watanabe, Serizawa, and Udas (2004) the sand spit significantly changes its configuration under changes in the wave field, which agreed with Thomas et al. (2011) work on a 262 yr record of bathymetric maps. They showed that certain spit formations can grow in the general direction of predominant longshore sediment transport, but can also erode commensurate with either a diminution of updrift sediment supply or changes in seabed and sandbank orientation. The spit may then become wave aligned and continue to grow in a different direction.

Laugharne Township, Carmarthenshire, South West Wales, is located in Carmarthen Bay (Fig. 1a and b) on the northwest Bristol Channel. It is in the lee of Ginst Spit at the junction of three rivers (Towy, Taf and Gwendreath) in a lowland area which has a history of flooding. There have been no assessments as to whether the primary influence in this flooding is fluvial, tidal or a combination of both. Therefore, this work used historical aerial photographs, meteorological data, topographic field studies and wave modelling to assess evolution patterns of Ginst Spit. Fluvial influence is significantly linked to flow and consequently, patterns of change were assessed alongside rainfall datasets to determine river contributions. Subsequently, results were analysed in conjunction with temporal flooding occurrences and corresponding spit morphology to determine cause and effect.

Physical and geological background

Carmarthen Bay is a shallow embayment which is bounded by the Gower Peninsula to the east and Giltar Point to the west (Halcrow, 2010, Fig. 1b). The coastal strip is approximately 70 km long and varies from extensive sand beaches to muddy tidal flats or rocky cliffs, while human use includes industrial, recreational, agricultural and residential activities (Barber & Thomas, 1989). To the west of Laugharne, Pendine Sands (Fig. 1c) forms the seaward part of an extensive, sandy coastal barrier (Jago and Hardisty, 1984) and this includes Ginst spit (Fig. 1d). Centrally placed within the bay and separating Pendine Sands from adjacent Cefn Sidan Sands is the Taf, Towi and Gwendreath estuary complex. Strong winds and tides generated in the Bristol Channel, together with north Atlantic swells contribute to a high energy wave environment (Allan, Tett, & Alexander, 2009). Dominant and prevailing south-westerly winds that expose the Bristol Channel to un-refracted North Atlantic waves ensure abundant wave action within these macrotidal, 7.5 m spring tidal range waters (Phillips & Crisp, 2010; Thomas et al., 2011). Offshore recorded dominant south to westerly waves average 1.2 m in height, with associated 5.2 s periods. However, south westerly storm waves can exceed 5.5 m with associated periods that range between 8 and 15 s (Thomas et al., 2010). Consequently, storm waves have historically influenced Ginst spit

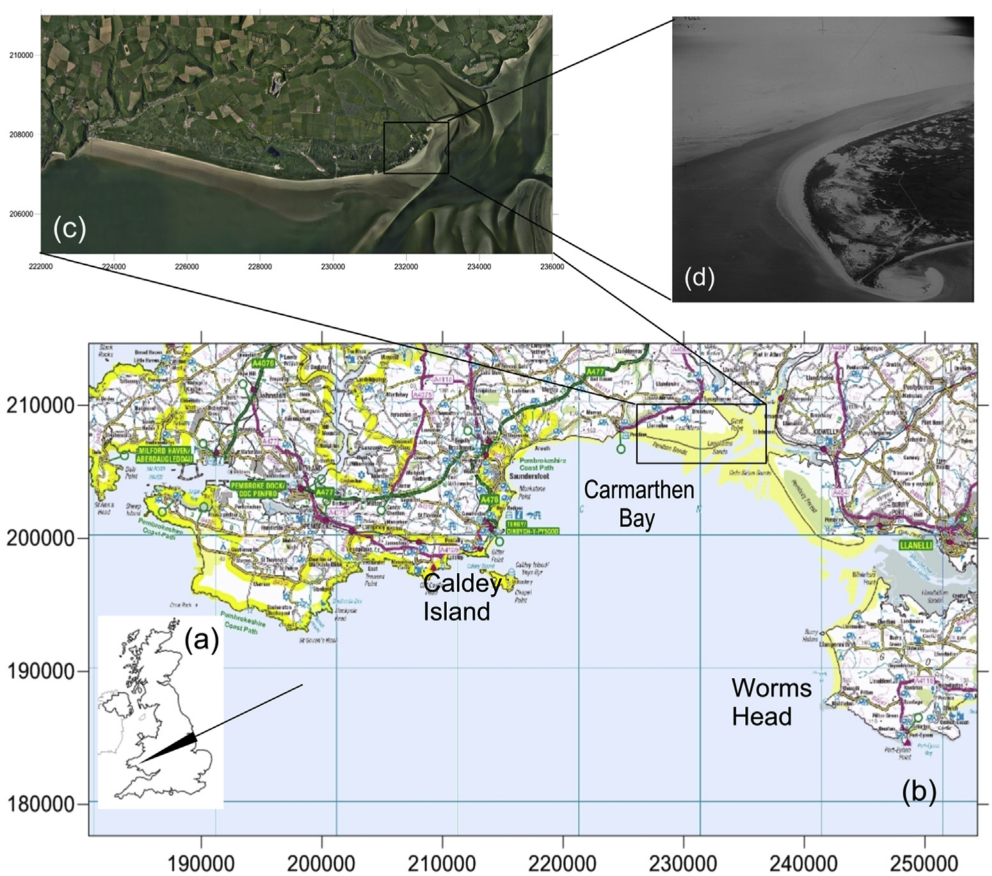

Fig. 1. Study area locality, a) United Kingdom, b) West Wales and Carmarthen Bay, c) aerial photograph showing Pendine Sands, d) oblique aerial photograph showing Ginst Spit.