Marine Geology 359 (2015) 148–162

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margeo

The influence of geomorphology and sedimentary processes on benthic habitat distribution and littoral sediment dynamics: Geraldton, Western Australia

Sira Tecchiato [a,*], Lindsay Collins [a], Iain Parnum [b], Alexandra Stevens [a]

[a] Department of Applied Geology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia
[b] Centre for Marine Science Technology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

ARTICLE INFO

Article history:
Received 6 March 2014
Received in revised form 6 October 2014
Accepted 7 October 2014
Available online 7 November 2014

Keywords:
Benthic habitat mapping
Coastal geomorphology
Cool water carbonates
Multibeam backscatter
Geraldton
Western Australia

ABSTRACT

Understanding of the processes regulating sediment transport, accumulation and erosion requires an appropriate mapping of coastal geomorphology, seabed sediments and benthic habitat distribution to allow management issues to be identified, understood and addressed. In this study multibeam echo-sounder data were used to map shallow water geomorphological features and the spatial distribution of benthic habitats, with the support of underwater imagery for ground truthing the acoustic data. At Geraldton, sediment analyses have revealed a dominant biogenic nature, with modern carbonate sedimentation linked to the seagrass and macroalgal carbonate factories colonising these shallow (<30 m) coastal embayments. Whilst seagrasses are common on sheltered hardgrounds blanketed by fine sand, macroalgae were found on high energy limestone reefs. The distribution of sand bar and sheet systems is regulated by wave induced sediment transport with the influence of pre-existing seabed topography. Exposure to wave energy, seabed geomorphology and sediment characteristics is closely related to the distribution of benthic habitats and sand substrates, highlighting the value of an integrated analysis of these parameters. The capability of multibeam echo-sounder backscatter data to discriminate between seagrass meadows, macroalgal communities and sandy substrates was also evaluated and the acoustic response from the seabed was better explained by considering together seafloor geomorphology and biota type, as both these parameters influence backscatter strength.

1. Introduction

The understanding of littoral processes and the correct addressing of management issues are based upon the identification of coastal sediment cells and include a budgetary approach to study littoral sediment systems (Bray et al., 1995; Cooper and Pontee, 2006; Anfuso et al., 2011; Anfuso et al., 2013). Recently, an integrated approach which takes into account the characterisation of geomorphology, sediments, shoreline evolution and local hydrodynamics has been regarded as the most appropriate method for delineating littoral sediment cells (U.S. Army Corps of Engineers, 2002; Rosati, 2005; Cooper and Pontee, 2006; Anfuso et al., 2011). A study on coastal compartmentalisation by the Western Australian Department of Transport is ongoing along the state coastline and it aims to provide a framework for coastal management authorities by defining natural management units. At the request of coastal managers we investigated the relationships between coastal geomorphology, benthic habitats and sediment properties, and the strategically important Geraldton area in the central part of the coast of Western Australia was chosen as a case study.

Previous sediment budget studies used side scan sonar to investigate seafloor geomorphology (Cooper and Pethick, 2005; Rosati, 2005) but this instrument does not record bathymetry data. Multi-beam echo sounder (MBES) data were collected in this study and have allowed the characterization of seabed geomorphology to be achieved at high detail. The understanding of underwater geomorphology and characterisation of seabed substrates reflects the influence on the seabed of the processes driving sediment transport (Cooper and Pontee, 2006; Velegrakis et al., 2007). Internationally, there is an emerging need to understand the linkage between geomorphic features, benthic habitats and sedimentary processes (Freeman and Rogers, 2003; Harris and Hughes, 2012; Harris, 2014). Geomorphological parameters such as seabed topography and hardness form useful surrogates where seabed structure and the distribution of benthic organisms are linked, facilitating the use of habitat mapping techniques (Heyman, 2011; Heyman and Wright, 2011). For example, limestone ridges have often been utilised as a surrogate for habitat development (Ryan et al., 2007a; McArthur et al., 2010) and previous studies of the south Australian coast (James and Bone, 2011) have partitioned warm-temperate macroalgal and seagrass communities on the basis of the substrate types, i.e. macroalgae

* Corresponding author. Tel.: +61 417 365 664 (Mobile).
E-mail addresses: sira.tecchiato@postgrad.curtin.edu.au, sira.tecchiato@gmail.com (S. Tecchiato), L.Collins@curtin.edu.au (L. Collins), I.Parnum@curtin.edu.au (I. Parnum), M.A.Stevens@curtin.edu.au (A. Stevens).

http://dx.doi.org/10.1016/j.margeo.2014.10.005
0025-3227/

colonise the lithic substrates and seagrasses occupy adjacent sandy substrates. In contrast, in the Mediterranean Sea seagrasses can be associated with sedimentary substrates and hardgrounds with the plant rooted in bedrock depressions (De Falco et al., 2010). Western Australian seagrass habitats occur over a range of sediment types (Carruthers et al., 2007) and here we present new data on the geomorphic features and sediments underlying the distribution of temperate water benthic habitats. This paper presents the results of geomorphology, habitat and sediment mapping, developed for the shallow coastal embayments (<30 m) off Geraldton. This paper aims to: (1) provide insights into how geomorphic features influence littoral sediment dynamics; (2) explore the relationship between shallow water geomorphology and sedimentary processes and the distribution of benthic habitats; and (3) investigate the capability of MBES backscatter (BS) data to discriminate between temperate water benthic habitats and substrates.

1.1. The usage of multibeam echo-sounder bacsckatter data to map seagrass and macroalgal communities

The Geraldton coastal platform is colonised by seagrass and macroalgal communities, and these communities are recognised contributors to the sediment budget of the southern and western Australian coastal embayments (Short, 2006a; Short, 2010). The mapping of seabed environments is a fundamental tool for coastal and marine management (Mumby and Harborne, 1999; Pickrill and Todd, 2003; Ryan et al., 2007a; Cogan et al., 2009), and the preservation of benthic habitats recognised as sediment sources and seabed stabilisers such as seagrass and macroalgal communities should be ensured. A MBES survey was carried out in this study to provide high resolution bathymetry and BS data, which were used for seabed characterization. It is well known that acoustic BS can be used to infer seafloor physical and biological properties (or benthic habitats), such as by exploiting the backscatter versus incidence angle curves (Hughes Clarke et al., 1997; Parnum, 2007). For instance, BS strength has been found to be directly proportional to sediment grain size and surface roughness (for unvegetated substrates; Hughes Clarke et al., 1997; Goff et al., 2004; Ferrini and Flood, 2006; Parnum, 2007; Fonseca et al., 2009). High BS levels are to be expected from hardgrounds and gravel dominated substrates, as they have a large surface roughness and high acoustic impedance (Parnum, 2007; Rzhanov et al., 2012). Acoustic scattering from seagrass and macroalgae is poorly understood compared to rock and sediments (De Falco et al., 2010). Possible reasons speculated for high BS levels from marine flora compared to surrounding uncolonised seafloor areas include gas bubbles, foliage and dense root structure (Parnum, 2007; Wilson and Dunton, 2009; De Falco et al. 2010). This paper provides new data on the relationship between MBES BS strength and a range of sandy and rocky seabed features, as well as macroalgal and seagrass colonised substrates with varying percent cover assessed on the basis of ground truth data.

2. Regional setting

A sediment budget study was undertaken at Geraldton, an expanding urban and industrial complex, which serves an essential port facility of the state of Western Australia. The important coastal infrastructure and the coastal erosion that is impacting the town beaches required a detailed environmental characterisation of the study site to support identification of sediment transport pathways. Similar situations are reported elsewhere in the state as maritime transport is fundamental for sustaining local and international commercial activities.

The western margin of Australia is one of the classic passive continental margins in the world with a ~50 km wide continental shelf (Collins, 1988) and a shallow 10 m deep coastal platform which extends several kilometres from the shore. Due to the geomorphology of the coastal platform, dredging activities are common to allow for increased ship loadings. Despite the frequency of dredging and its impact on the adjacent coast, little research has been carried out on the relationship between coastal geomorphology, sediments, benthic habitats and metocean interaction as most of the previous investigations carried out in the state focused on deeper regions of the continental shelf.

2.1. Physical environment

The study area encompasses the city and port of Geraldton, approximately 400 km north of Perth in Western Australia (Fig. 1). Shoreline salients, cuspate forelands and tombolos are common coastal sedimentary landforms of the Western Australian coast, and along the central west coast are developed in association with semi-continuous Pleistocene reef systems located up to 15 km from the shore (Sanderson and Eliot, 1996). The interaction between local sediment transport and offshore limestone reefs at Geraldton has resulted in the formation of the Point Moore tombolo which separates the coast into two main embayments, both analysed in this study. Of note are a significant mobile dune system towards the southern end of the study area (Southgate Dune) and a small river (Chapman River) occasionally supplying sediment to the coastal system and contributing to the formation of sand bars offshore.

2.2. Coastal processes

Geraldton experiences a Mediterranean-type climate, with the temperature averaging 20 °C in the winter months with most of the yearly rainfall in this period (May–August) and an average temperature of 32 °C in the dry summer months.

The west coast of Australia has a predominance of moderate to strong winds throughout much of the year. The wind climate at Geraldton is highly seasonal with two principal wind regimes: SSW during summer and NE during winter with lighter winds. Winter storms are from the NNW. During warmer months the wind climate at Geraldton is dominated by the effects of the land–sea interface and by the position of the sub-tropical ridge, which generates winds with an easterly component overnight and for the morning offshore land breezes, whilst sea breezes from the S to SW dominate the afternoon. Summer sea breezes often reach 25 knots (46 km/h) or more near the coast.

The Geraldton coast is wave dominated with main wave direction from the SW. Swell wave heights range predominantly between 1 and 1.5 m with superimposed seas with heights mainly in the range of 0.5–1.5 m. The mostly wind driven coastal current circulation is frequently northward oriented in the summer (Short, 2010) but reversals to this circulation pattern occur in winter with offshore sediment transport due to wave refraction correspondently to the offshore limestone ridges.

3. Methods

3.1. Data collection

Over 100 sediment samples were collected in November 2009 from 0 to ~30 m depth along a 1 km × 1 km spaced grid (Fig. 1). During the survey, it was found that the sediment/water interface was sufficiently consolidated to impede grab sampling; consequently a steel pipe dredge was used. The pipe dredge sampling operations involved boat drifting; this combined with the accuracy of the positioning system resulted in positioning accuracy of ±20 m for the sediment samples.

A MBES survey was carried out in November 2010 using a Western Australian Department of Transport hydrographic vessel. The survey area covered the embayments north and south of the city of Geraldton, between 2 and 30 m depth. Data were acquired using a Reson Seabat 8101 MBES system, which operates at 240 kHz and has a swath width 150° across track and 1.5° along track.