Occurrence of tidal sand waves in a Brazilian coastal bay: the Sepetiba case

Mariana T.C. Pardal *Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brasil – maripardal@gmail.com*
Josefa V. Guerra *Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brasil – josie.guerra@gmail.com*
Pieter C. Roos *University of Twente, Enschede, The Netherlands – p.c.roos@utwente.nl*
Suzanne J.M.H. Hulscher *University of Twente, Enschede, The Netherlands – s.j.m.h.hulscher@utwente.nl*

ABSTRACT: Sepetiba Bay is one of the most important bays in southeastern Brazil mainly because of several economic activities such as fishing, tourism, and the presence of important ports. The occurrence of sand waves in Sepetiba Bay was studied using two multibeam bathymetric datasets obtained during surveys carried out between November and December 2011, and in December 2012. The sand wave field was divided into seven areas and 104 individual sand waves were identified with heights varying between 0.1 and 5.7 m and wavelengths ranging from 9 to 228 m. Coarse sands occur in the crests whereas medium to fine sands are found in the troughs. Near-bed current velocities measured at the northern limit of the sand wave field reached 1.02 m/s during spring tides, and exhibit flood dominance. In this work were used a linear process-based sand wave model to improve the understanding about their occurrence and the relation with environmental

1 INTRODUCTION

Bedforms are common features in the bottoms of shallow seas where tidal currents are present and sands are available. Here we focus on features known as subaqueous dunes or tidal sand waves (Terwindt, 1971).

The presence of bedforms in Sepetiba Bay was first mentioned by Belo (2002) and later studied by Oliveira (2013). Belo (2002) described small bedforms in the entrance of the bay (height ranging from less than 0.2 until 0.55 m and wavelength between 8.6 and 60 m).

Oliveira (2013) was the first to conduct an observational study focused on the subaqueous dunes from Sepetiba Bay. The author identified 62 subaqueous dunes distributed close to Sepetiba's bay main navigational channel with heights varying between 0.2 and 4.6 m and wavelengths ranging from 18 to 164 m. In his study, Oliveira (2013) could not determine if the bedforms are still fully active or not.

The available bathymetric data show a great diversity in sand wave morphology occurring in a small area (≅ 34 km^2). Therefore, the main goal of this study is to understand how this morphological variability is related to the modern environmental characteristics and which conditions favour the formation and development of such bedforms. Here, we first present the study area (§2), followed by data and methods (§3), some first observational and modelling results (§4), as well as a discussion and conclusions (§5).

2. 2 STUDY AREA

a. 2.1 General Description

Sepetiba bay is located in the southern part of Rio de Janeiro State between the coordinates 043º30'W/44º10'W and 22º50'S/23º05'S. It has an ellipsoidal shape being 40 km long and 16 km wide (Villena et al., 2012) (Fig. 1). epths are mostly less than 10 m except in the main channel area (water depth greater than 25 m maintained by dredging).

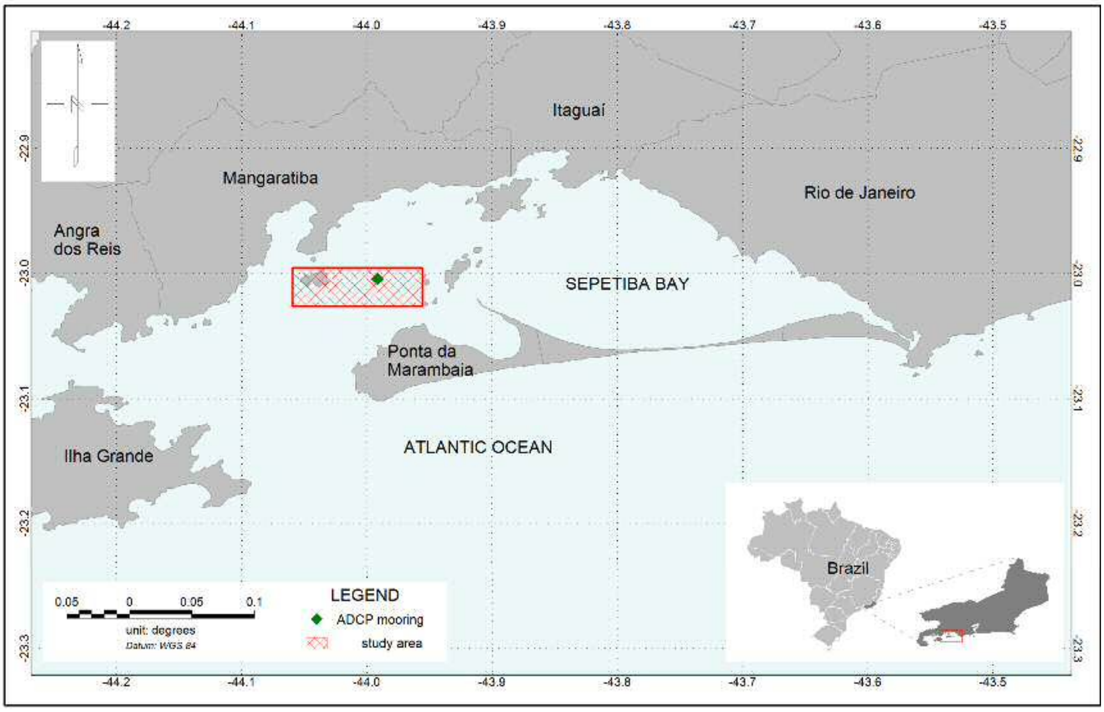

Figure 1: Sepetiba bay location, study area, and ADCP mooring position.

Its origin is associated to structural events occurred during the Cenozoic (Zalán & Oliveira, 2005), whereas its geologic evolution and present morphology are related to sea level oscillations during the Quaternary (Villena et al, 2012).

According to Signorini (1980), the circulation mechanism follows the partially-mixed estuarine system with components of gravitational, residual and tidal circulations.

In Sepetiba Bay, there is a lag between the tide wave in its entrance and its head, generating both sea level elevation gradients and strong tidal currents (Fragoso, 1999). Winds acting on the continental shelf can have an important role in this area affecting the currents in the interior of the bay (Fragoso, 1999). Vertical profiles of the currents were documented at the northern limit of the study area and revealed that floods are up to 2 hours shorter than ebbs and are associated with the strongest flows (Fonseca, 2013).

The bay is covered by sediments ranging from clay to sands, which have multiple sources such as (i) past and modern rivers flowing into the bay, (ii) the nearby shelf, and (iii) coastal erosion. Sands are more abundant between Ilha Grande and Ponta da Marambaia, being a mixture of modern and relict deposits (Fig. 2).

The study area is approximately 34 km^2 (red rectangle in Fig. 1); it is limited eastward by Jaguanum island, southward by Ponta da Marambaia and north/westward by Guaíba island, encompassing sectors of the main navigation channel.

3. 3 DATA AND METHODS

a. 3.1 Available data

In this study, the data acquired during three multibeam bathymetric surveys (Fig. 3) and five Teledyne-RDI 600 kHz ADCP moorings was used. The first two multibeam surveys were carried out in December 2010 and November 2011 by the Brazilian Navy. The data was acquired with a Kongsberg EM 3000 multibeam echosounder. The third survey was carried out in December 2012 by Microars, working for the mining company Vale, using an R2Sonic 2024 multibeam echosounder.

The horizontal resolutions in these datasets are different: the first one has a 0.3 m resolution for both horizontal directions (X and Y) while the second one has a 1.44 m resolution in the same directions.

The ADCP dataset corresponds to five moorings deployed intermittently between December 2010 and September 2012 for 3- to 4-month long periods in the main navigation channel (Fig. 1).

3.2 Bathymetric data analysis

For this work, all the bathymetric datasets are provided in XYZ format. The analysis of these data was carried out using Geosoft Oasis montaj 8.5.5.

Firstly, the data was gridded using the minimum curvature method respecting the X-Y spacing of each dataset resulting in a surface model. The study area was divided into seven areas with distinct properties in terms of dune occurrence and dune morphology.

For each area, one or more transects were extracted obtaining a total of 12 transects (white traces in Fig.3). The dunes in each transect were identified by visual inspection revealing the characteristics of each subaqueous dune (height H, wavelengths L) and calculated the parameters H/L, L/H (ripple index) and the asymmetry (Knappen, 2005).

Both characteristics and parameters were plotted in scatterplot graphs to correlate each pair of data using Golden Software Grapher 12.

3.5 Current data

The ADCP mooring was deployed with transducers on an upward-looking configuration, positioned 0.64 above the seafloor.

The water column was sampled with 0.5 m bin sizes and four-minute sampling rate. The blank distance corresponds to 0.88 m, then measurements were taken between 2.26 m above the bottom and 3 m below the surface.

b. 3.4 Sand wave modelling

The modeling used in this work is the process-based morphodynamic model developed by Campmans et al. (2017) which uses linear stability analyses to explain sand wave formation considering environmental parameters such as currents and waves.

The modelling process can be briefly described in five steps: (1) model formulation, including all necessary hydrodynamic and sediment parameters to describe the problem; (2) basic state, which consists of a flat bed without sediment movement and no spatial variation; (3) perturbation of the basic state expressed as a superposition of modes with a sinusoidal structure; (4) calculation of the linear response to this perturbation leading to growth and migration rates of these modes and (5) interpretation of the model results. In particular, the so-called *fastest growing mode* provides insight in the preferred sand wave characteristics.

4. 4 RESULTS

From the bathymetric data 104 subaqueous dunes were identified with heights varying between 0.1 and 5.7 m and wavelengths ranging from 9 to 233 m. The crests of the subaqueous dunes are located in an average depth of 17.2 m.

Sand wave morphology is not spatially uniform: different shapes are observed. Small bedforms superimposed to the sand waves are present in some areas. The crests are oriented in different directions.

The sand waves occur in depths ranging from 4 to 31 metres. Furthermore, the available sedimentary record show that sand waves are formed by very fine to coarse sands. Finally, the current data and sand wave modelling are work in progress and no results are currently available.

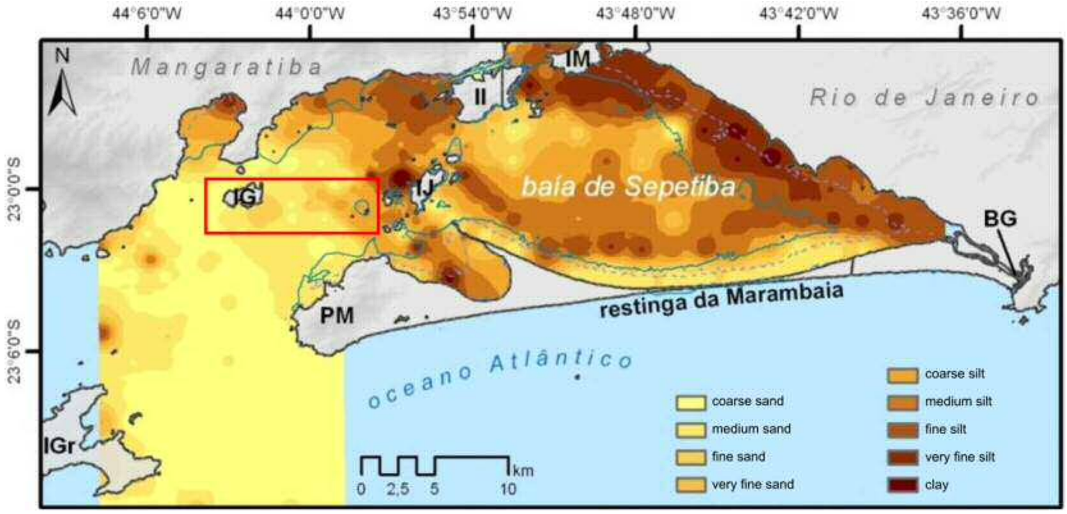

Figure 2: Sediment distribution in Sepetiba bay and study area (red rectangle) (modified from Carvalho, 2014)

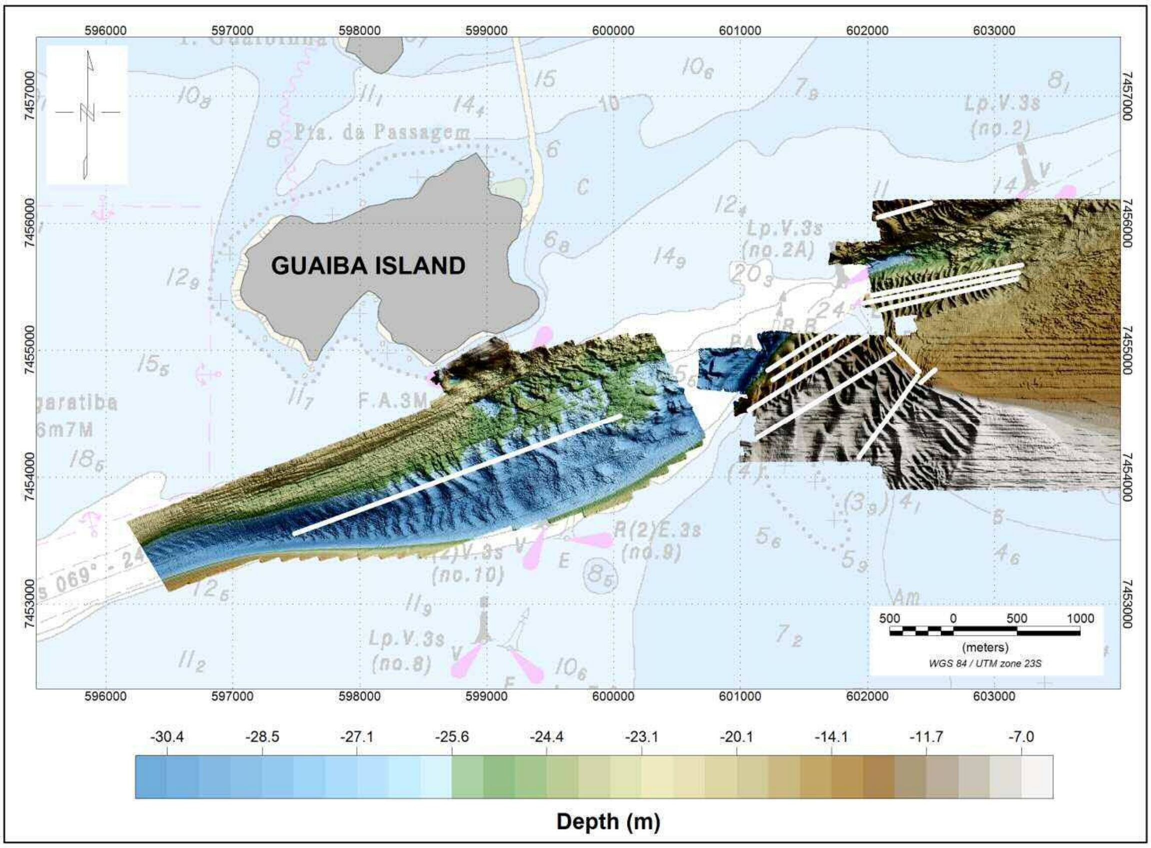

Figure 3: Available bathymetric data superimposed on the nautical chart and transects position (white traces). Southward from Guaiba island: VALE data; eastward: Brazilian Navy data.

5 DISCUSSION AND CONCLUSIONS

The sand waves are present in a small area of the bay (but it is not possible to say if it is restricted to this area) with a strong morphological variation, e.g. with bedforms disappearing abruptly in the east sector.

According to previous studies (see Fig. 2), in this sector the sediments become finer and the navigation channel narrower (Fig. 3).

The greatest sand wave heights occur in the areas with an average depth of 8 metres (Fig. 3) while the longest wavelengths occur in the deepest areas.

The crest orientation and shape variability suggest a complex hydrodynamic scenario acting in the study area. The current data and the modelling results will help to better describe and understand the processes associated with the sand wave presence in this area.

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