Cobble beaches in oceanic islands: how they react to hydrodynamics and location in the island?

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Introduction

Hydrodynamics play an important role in littoral structure and dynamics (Osborne, 2005). In beaches formed by larger particles, such as gravel, pebbles or cobbles, the influence is visible in the variation of the beach slope (Pedrozo-Acuña et al., 2006). There is, however, little information on the effects of wave intensity on the beach biological communities.

In this study the following hypotheses are tested:
i) The hydrodynamics affects the beach profile;
ii) The macroalgae and invertebrate communities are affected by the hydrodynamics independently of the beach localization;
iii) There is seasonal variation in the distribution and abundance of macroalgae and invertebrate communities.

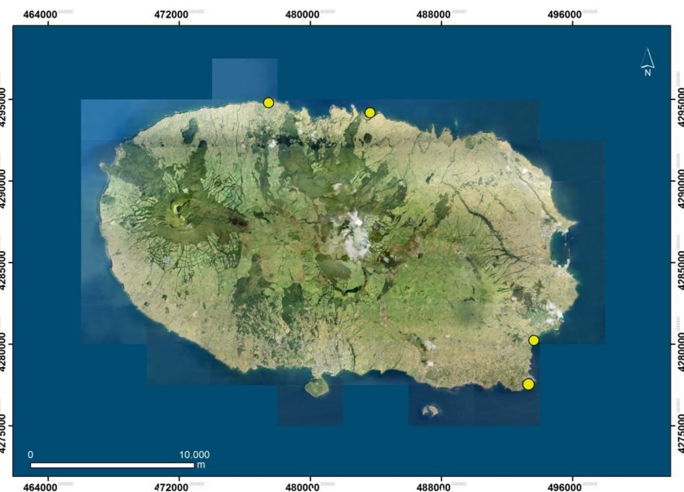

Fig.1: Island of Terceira with sampling sites in yellow circles.

Fig.2: Profile equipment.

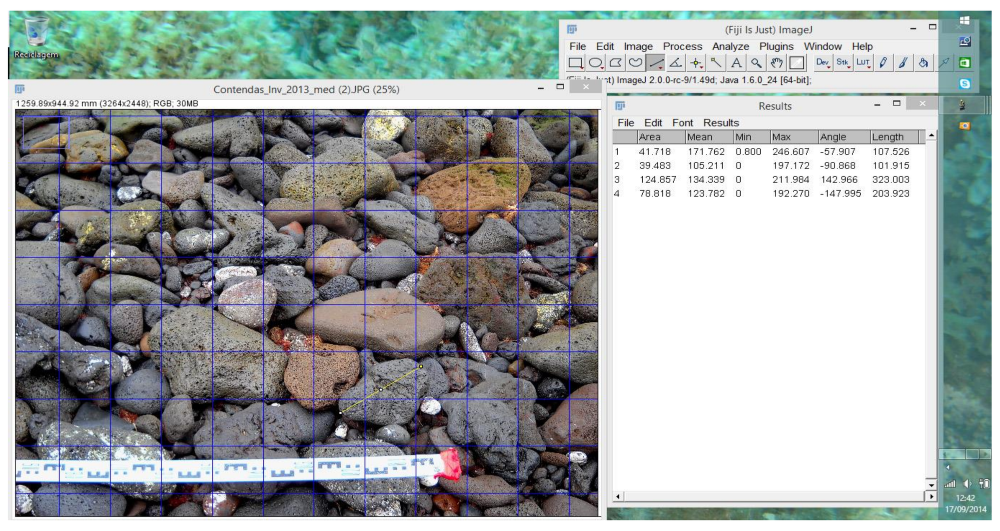

Fig.3: Digital measurement of cobbles.

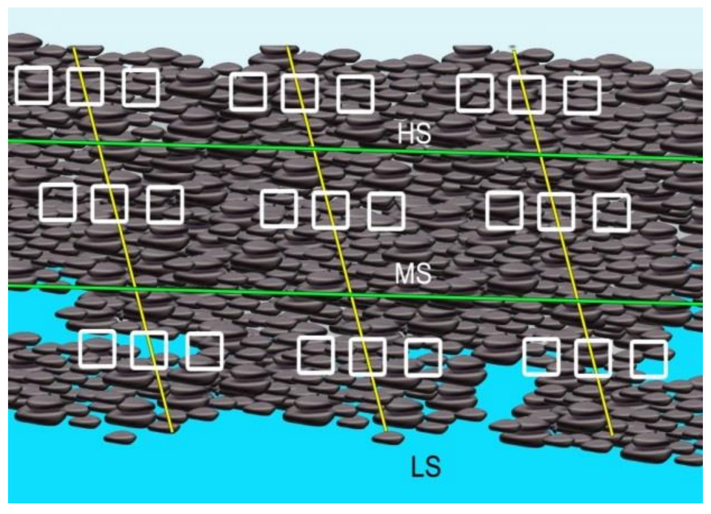

Fig.4: Scheme of the biological sampling.

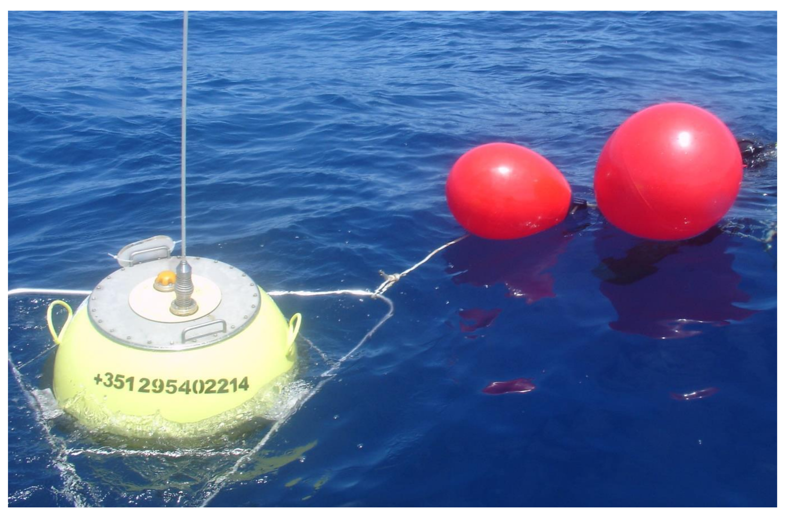

Fig.5: Wave measuring buoy.

Material e Methods

The study was made in Terceira Island (Azores, Fig.1).

Four cobble beaches were sampled (2 in the north shore – more exposed, 2 in the east shore – less exposed, Fig.1) during summer 2013 and winter 2014. Three profiles were made of each beach in each season (Fig.2). Based on the distribution limits of littorinids, barnacles, green algae, turf and algae fronds each beach was vertically divided in three levels. At each shore level 90 cobbles were photographed, digitally measured(Fig.3) and assigned to size classes according to the Wentworth grain size classification (Wentworth 1922).

At each shore level, algae percent cover was determined and invertebrate counts were made using 625 cm^2 quadrats (9 replicates per shore level, Fig.4). Analysis of similarity between shore level, beach, coast and season was conducted using Primer-E 5.

Using hourly wave data (maximum height, period and direction) collected by an ocean buoy located northeast of Terceira island (Fig.5), the number of days with waves from each quadrant was counted, as well as the overall daily wave maximum height.
Data was statistically analyzed through ANOVA (Underwood, 1997).

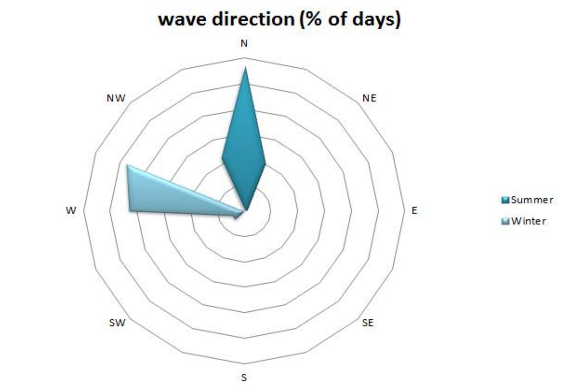

Fig.6: wave direction in Terceira during summer and winter months.

Table 1. ANOVA analysis of coasts in the summer and winter and between seasons at the two coasts studies.

Source of variation	SS	DF	MS	F	P value	critic F
seasons	0,000605	1	0,000605	0,70280633	0,41175	4,351244
coasts	0,018844	1	0,018844	21,8900194	0,000144	4,351244
interactions	0,002699	1	0,002699	3,13499709	0,09187	4,351244
within	0,017217	20	0,000861			
Total	0,039365	23				

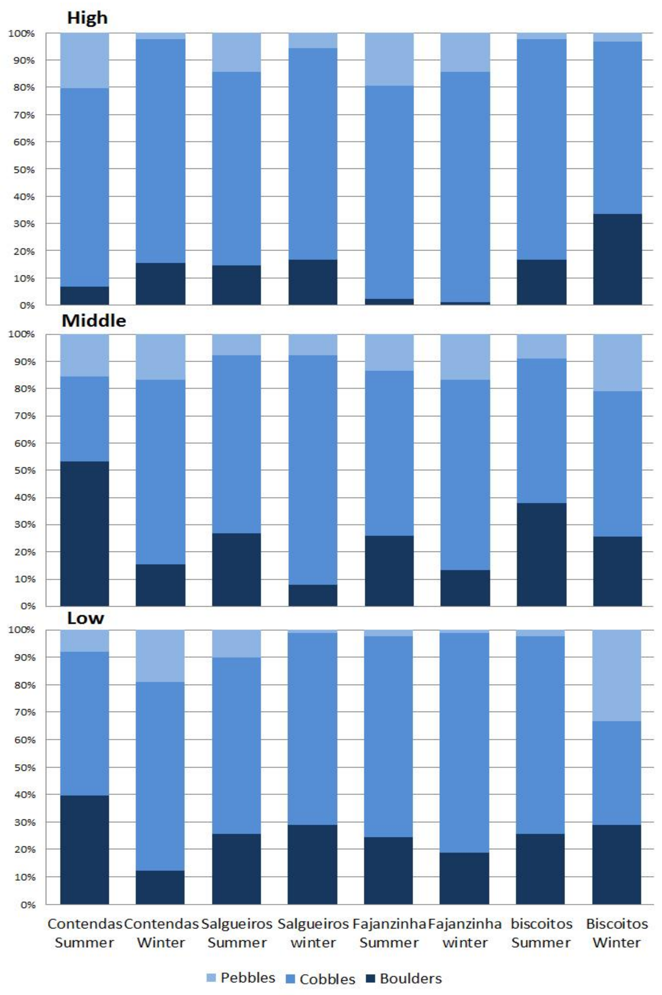

Fig.7 : Substrate particles abundance at each beach in the summer and in he winter.

Table 2. species lists of macroalgae and invertebrates in the studied beaches.

algae

Chlorophyta	Ochrophyta	Rhodophyta
Ulva rigida	*Colpomenia sinuosa*	*Asparagopsis armata*
Enteromorpha compressa	*Endarachne Binghamiae*	*Gelidium spinosum*
Enteromorpha prolifera	*Padina pavonica*	*Jania rubens*
Enteromorpha sp.	*Halopteris scoparia*	*Corallina elongata*
Blidingia sp.		*Litophyllum tortuosum*
		Nemoderma tingitanum
		Falkenbergia rufalanosa

invertebrates

Annelidae	Arthropoda	Mollusca
Oligochaeta 1	*Saphaeroma serratum*	*Myosotella myosotis*
Polychaeta 1	*Forficula auricularia*	*Littorina striata*
Nereis diversicolor	*Bdella sp.*	*Melarhaphe neritoides*
Eupolymnia nebulosa	*Ligia italica*	*Ovatela. vulcanii*
Spirorbis sp.	*Anfipoda a)*	*Cardita calyculata*
Pomatoceros sp.	*Anfipoda b)*	*Bittium reticulalum*
	Chthamalus stellatus	*Pedipes pedipes*
		Patella candei

Table 3. Anosim analisis of macroalgae communities in the studied beaches.

shore level	analysis	season	R	P
Low Shore	Between coasts	Summer	0,04	0,1%
		Winter	0,79	0,1%
	Between seasons	2 coasts	0,13	0,2%
		North	0,52	0,2%
		East	0,01	2,8%
Middle Shore	Between coasts	Summer	0,01	2,5%
		Winter	0,10	1,9%
	Between seasons	2 coasts	0,07	0,4%
		North	0,07	6,1%
		East	0,04	0,0%

Results

Waves

Summer waves were dominantly from the north and northwest with an average height of 1.7m, reaching a peak of 3.6 m on June 27. Winter waves were dominantly from the west with an average height of 3.43m and peaking in December 29 with 5.38m (Fig.6).

Beach profile

Significant differences (two way ANOVA, Bonferroni correction) were found between the northern and the eastern beaches in the summer season ($F= 0.702$; $p= 0.412$, table 1), slope was higher in the northern shore (between 0,171 and 0,266 in the north and 0,103 and 0,158 in the east). In the winter there was no significant variation between coasts.
The distribution of grain size classes in the middle shore varied between seasons, with an increase of the boulder % in summer and of the cobble % in the winter. Pebbles were scarce with the exception of Biscoitos in the winter (Fig.7).

Biological communities

Beach location

Calcareous turf and frondose species (e.g. *Coralina elongata*, *Gelidium spinosum*. and *Colpomenia sinuosa*) were more abundant on the east coast and there were few areas without algae cover, while in the north a thin cover of green algae and non-calcareous turf was dominant.
21 species of invertebrates were identified (8 molluscs, 7 artropods and 6 annelids,Table 2). Results showed little abundance of specimens by quadrat and a non-equitable distribution of specimens. In addition 4 species of crabs were identified in all beaches outside the quadrat area, and the anemone *Actinia equina* was found in Contendas and Salgueiros also outside the quadrats.

Seasonal variation

Differences in algal cover between seasons were significant in the north coast, due to the higher abundance of areas without algae cover in the summer and a lower abundance of non-calcareous turf in the winter. In the middle shore there were no significant differences regarding either coasts or seasons. Data analysis revealed that in the low shore differences between coasts in algal species abundance were significant in the winter (Table 3).

Discussion e conclusions

Wave action registered its peak in the northwest during the winter season, but heavy wave action was permanent along the year in the northern shores. This fact could explain the small differences between seasons in the particle composition of the northern shores, especially at Fajanzinha where sediments are continuously being revolved by the surge.

The hydrodynamics also influence the macroalgae communities: in the exposed northern shore the more resistant algal growth forms such as turfs and crusts were dominant, whereas frondose species, less resistant to wave energy, occurred mainly on the eastern coast beaches. This was reinforced by the presence on the east coast of the anemone *A. equina*, a species that in the Azores is common in less exposed bedrock intertidal and tide pools.

Differences were less conspicuous in the invertebrates probably due to the low number of specimens counted at each quadrat.

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