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Geomorphological processes of a Mediterranean urbanized beach (Sardinia, Gulf of Cagliari)

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ABSTRACT

In this study, we present a comprehensive map of a microtidal wave-dominated beach system based on an interdisciplinary sea–land approach and with the purpose of supporting a sustainable and successful beach management. The study area is located in a highly urbanized/industrialized coastal sector of the W side of Cagliari Gulf (S Sardinia, W Mediterranean). In the [Main Map](#) (1:15,000 scale), static and dynamic features of the beach system and adjacent inner shelf are divided into thematic sections, including geomorphological elements, bathymetry, sedimentological distribution, benthic habitat (mainly *Posidonia oceanica* meadow), hydrodynamics and anthropogenic features. The map constitutes an example of multidisciplinary benchmark to allow for long-term planning and management of this highly urbanized beach system. It is able to provide a substantial scientific support to policy-makers towards environmental restoration and sustainable development.

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1. Introduction

Urbanized beaches are complex systems where the increasing anthropological development implicates an environmental transformation (Jiménez, Gracia, Valdemoro, Mendoza, & Sanchez-Arcilla, 2011). These areas, subject to sea level rise linked to climate change on one side and intense urbanization on the other side, have historically been managed with insufficient information on coastal geomorphological processes. Consequently, human activities limit the flexibility of a beach leaving no space for normal sediment dynamics (Nordstrom, 2000). Urbanized beaches may be subject to an increasing deterioration in environmental quality as a consequence of human activity. Since eliminating human activities from sensitive coastal areas is an unattainable task, there is growing evidence that sandy beaches have to be properly studied and managed to ensure that human use of the coast and environmental protection coexist (Defeo et al., 2009; De Muro, Pusceddu, Buosi, & Ibba, 2017; Schlacher et al., 2007).

The Gulf of Cagliari (S Sardinia, W Mediterranean; [Figure 1](#)) encompasses two beach systems, Giorgino – Villa D’Orri at W and Poetto at E, both affected by different anthropogenic impacts. The beach system located to the W (Giorgino – Villa D’Orri; [Figure 1](#)) is mainly characterized by residential development

that has modified the coastal morphology, in particular the fluvial system. In addition, the presence of an oil refinery (one of the largest refineries in Europe), industrial and port activities (such as dredging, dumping, movement of ships, containers and other cargo, loading and unloading of ships and containers, anchorages, loading berths, fishing, discharge of municipal untreated sewage) are the cause of turbidity, pollution, toxicity and erosion. The main human modifications are reported in [Table 1](#).

The environmental stress of the beach system located to the E of the gulf (Poetto beach; [Figure 1](#)) is especially linked to increasing residential development of the city of Cagliari and its hinterland (about 500,000 inhabitants), touristic pressure and nourishment works (Brambilla, van Rooijen, Simeone, Ibba, & De Muro, 2016; De Muro, Ibba, Simeone, Buosi, & Brambilla, 2017).

In this paper, we focus on geomorphological processes and anthropogenic modifications of the coastal sector that extends between Cape S. Elia (to the NE) and Sarroch (to the SW) and includes Giorgino and Villa D’Orri beaches ([Figure 1](#)). In this context, our study based on interdisciplinary sea–land approach is a key tool towards the development of a sustainable and successful beach management plan (Buosi et al., 2017;

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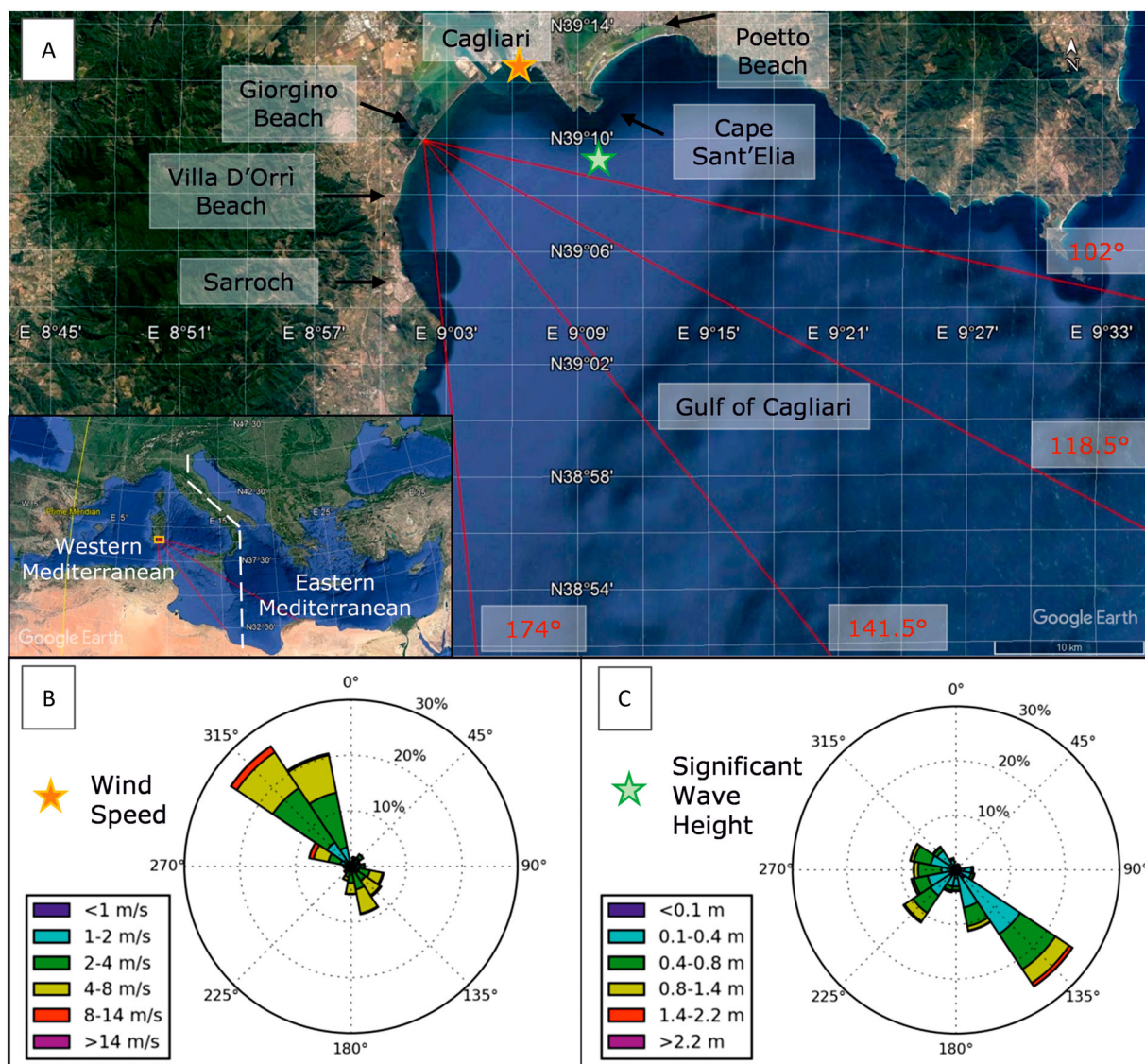


Figure 1. Geographical setting of the study area, located in the Western Mediterranean Sea, Gulf of Cagliari (A), including the wave exposure angles (referred to the $N = 0^\circ$) and fetch (red lines). Wind speed and direction (B) from Cagliari station of the national tidal monitoring network (location: orange star); significant wave height and direction (C) at the NOAA hindcast dataset point (location: green star).

Pennetta et al., 2016; Tintoré, Medina, Gómez-Pujol, Orfila, & Vizoso, 2009).

This paper aims to (1) describe static and dynamic coastal processes deriving from the interaction between morphodynamics, eco-geomorphological setting, sedimentary facies and human interventions; (2) provide a multidisciplinary benchmark for the medium- and long-term planning of urbanized beach management.

Table 1. Main human modifications of the study area.

Human modification	Period	Sector
Establishment of the Port of Cagliari	1930s	6
Establishment of the large industrial complex (e.g. oil refinery)	1960s	at SW of 1
Stabilization of lagoon mouths	1960s	5
Construction of the Canal Harbour (Porto Canale)	1970s	6
Construction of the Syndial pier (ex-Rumianca pier)	1970s	5
Residential urbanization of the Frutti D'Oro area downstream of the river San Gerolamo	1980s	3
Construction of groynes	2014	3

2. Study area

The studied beach system, classified as a microtidal wave-dominated, located in S Sardinia (W Mediterranean Sea) in the W side of the Gulf of Cagliari ([Main Map](#)), extends for 11 km and includes two areas, called Giorgino and Villa D'Orri beaches, developed on a SW-NE axis ([Figure 1](#)). Prior to the development of the city of Cagliari (twentieth century), a continuous aeolian, cross- and along-shore sediment supply existed across the studied embayments ([Appendix 1](#)). This sediment input was interrupted as a consequence of urban development. Today, the sediment input is mainly siliciclastic from the Santa Gilla lagoon towards the inner shelf of Cagliari Gulf ([Appendix 1](#)). In the E section of the bay, Cape S. Elia promontory provides mainly carbonatic and siliciclastic sediment through cliff erosion. An authigenic bioclastic sediment input comes from seagrass meadow ([VV.AA., 2013, 2016](#)).

Figure 1(A) shows the principal wave exposure angles of the study area and the corresponding fetches (red lines, Figure 1(A)), defined as the distance between the coastline of the investigated region and the offshore nearest land. All possible directions for approaching storms range from 102° to 174°. However, the dominant geographical fetch (longer than 500 km) is found between 118.5° and 141.5° (0° = North).

The prevalent winds recorded in the study area (Figure 1(B)) come from NW (27% of occurrence), in accordance with the general Mediterranean wind climatology (Lavagnini et al., 2005). However, the most energetic recorded storms come from SE (40% of occurrence, Figure 1(C)). This is because the beach system is naturally protected by Cape Carbonara to the E and Cape Spartivento to the W.

The Gulf of Cagliari is located in the southern part of the Cenozoic structures related to the Oligo-Miocene graben-system, between two Paleozoic tectonic blocks (Appendix 1; Carmignani et al., 2001; Casula, Cherchi, Montadert, Murru, & Sarria, 2001). The Quaternary continental shelf developed transversally to the tectonic trough, being fed by terrigenous sediments derived from the Paleozoic metamorphic basement and from Tertiary sedimentary and volcanic rocks. The inner shelf shows geomorphological hollows interpreted as the product of the paleo-river erosion during the Würmian low stand (MIS 4–2) (Orrù, Antonioli, Lambeck, & Verrubbi, 2004; Ulzega, 1995). Littoral-transitional depositional complexes (beach rocks) have been observed at –25, –40 and –55 m (De Muro & Orrù, 1998; Ulzega, Leone, & Orrù, 1986; VV.AA., 2016).

3. Methods

Results of integrated geomorphological, sedimentological and marine-coastal dynamic studies that were carried out following the methodological protocols developed by the Coastal and Marine Geomorphology Group – CMGG, University of Cagliari (e.g. Bartole, De Muro, Morelli, & Tosoratti, 2008; Batzella et al., 2011; De Muro, Batzella, De Falco, & Porta, 2010; De Muro, Pusceddu, & Kalb, 2010; Pusceddu et al., 2011), were used to build a Main Map (1:15,000 scale; Map 1) and 3 supplementary maps (one at 1:50,000 scale and two at 1:25,000 scale) that focus on topographic and morphobathymetric surveys (Map 2), sedimentary facies and ecological status (Map 3) and human impact and use (Map 4).

3.1. Shoreface

The morphology of the seabed is based on single beam bathymetry acquired using an Ecosounder/DGPS (Differential Global Positioning System) system interfaced with navigation software (frequency of 5 Hz).

The morphological surveys were carried out seasonally along 20 transects, which are spaced 500 m apart and extend from the shoreline to the inner shelf (up to –20 m; Map 2). The bar system is the result of the interpretation of profiles recorded during seven surveys and satellite images.

A total of 91 sediment samples was collected using a Van Veen grab (5 dm³ capacity) along the transverse transects (Map 2).

The mapping of benthic habitat is based on side-scan sonar, satellite images and underwater video data.

The ecological status of the seabed has been evaluated using the benthic foraminiferal diversity, following the classification scheme proposed by Bouchet, Alve, Rygg, and Telford (2012). The ecological status describes the deviation from reference environmental conditions by the subdivision into five status classes (high, good, moderate, poor and bad). High status is considered as an un-impacted reference or background condition. Alterations or contaminant levels correspond to moderate, poor and bad status if they have chronic, acute and severe acute ecosystem impacts, respectively (WFD, 2000/60/EC). For this purpose, 15 sediment samples were collected with a Van Veen grab. Each sediment was preserved in ethyl alcohol and treated with Rose Bengal (2 g of Rose Bengal in 1000 ml of ethyl alcohol) to distinguish living and dead specimens. In the laboratory, a constant volume of about 50 cm³ of sediment for each sample was treated following the procedure reported by Buosi et al. (2013a, 2013b) and Schintu et al. (2016).

The sedimentological, bathymetric, topographic and ecological data collected through field campaigns have been used as boundary conditions for the hydrodynamic modeling carried out with the open sources software DELFT3D (Deltares, <http://oss.deltares.nl/web/delft3d>).

3.2. Backshore

The topographical surveys were carried out along 20 transects, 500 m spaced (Map 2). The data were collected using DGPS NavCom in a GNSS (Global navigation satellite system) and/or StarFire (Navcom SF3040) system (frequency of 1 Hz).

Forty-six sediment samples were collected using a bailer along transects from the backshore (Map 2).

The main anthropogenic impact was identified in long-term scale by analysis of historical cartography, satellite and aerial images (from 1954 to 2014) and in short-term scale by field surveys.

3.3. Sediment analysis

The grain-size analyses were performed on the >63 µm fraction. Each sediment was dry sieved through a battery of sieves spaced at ¼ phi (ø) per unit (Wentworth,

1922). The pipette sedimentation method (Folk, 1974) has been used to analyze the <63 μm fractions. Textural parameters were calculated following the Folk and Ward (1957) protocols. The percentage of quartz, feldspars, lithoclasts and skeletal grains for each sample was established under an optical microscope (Lewis & McConchie, 1994).

4. Results

4.1. Shoreface geomorphology and benthic habitats

From the shoreline to the inner shelf, the bathymetric profiles show a shoreface that gently slopes down to -8 m isobaths in the central sector and to -4 m in the easternmost and westernmost sides (Map 3). A system of submerged bars alternated with troughs develops in the shoreface between 50 and 250 m from the shoreline.

Three main benthic habitats and substrate types were identified: (1) uncolonized sediment substrates dominate the seafloor in the intermattes and between the shoreline and the upper limit of the seagrass meadow. (2) A well-developed and dense meadow, mainly *P. oceanica*, occurs only in some areas at around -15 and -20 m in depth (Map 1). (3) A wide discontinuous seagrass meadow (mainly *Caulerpa prolifera*, *Cymodocea nodosa*, *P. oceanica*; between -4 and -20 m) with numerous intermattes (from -10 m to -15 m) has been recognized. This discontinuous meadow appears highly impacted by human activities (e.g. dredging, dumping, fishing, mooring, maritime traffic).

The ecological status of Gulf of Cagliari seabed, based on benthic foraminiferal assemblages (Appendix 2), is reported in Map 3. A moderate ecological status was found close to the Cape S. Elia promontory. The benthic foraminiferal assemblages showed a poor and bad ecological status in samples located in the discontinuous meadow between Giorgino and Villa D'Orri shoreface and inner shelf. All the investigated assemblages were mainly dominated by opportunistic and stress-tolerant foraminiferal species (*Ammonia* spp.

and *Bolivina* spp.). The foraminiferal fauna was characterized by low values of the Shannon-Weaver index (Shannon & Weaver, 1963; Appendix 2) which indicated a high impacted status of *P. oceanica* meadow.

4.2. Sedimentary facies

Six sedimentary facies were identified in the studied area (Map 3, Table 2) based on the grain-size, mineralogical and micropaleontological composition of the sediment (De Falco, De Muro, Batzella, & Cucco, 2011; De Muro, Ibba, & Kalb, 2016; Lecca, De Muro, Cossellu, & Pau, 2005).

Facies A is shore parallel, between about 0 and -6 m , and it is characterized by siliciclastic sand. Close to the Cape S. Elia promontory a calci-lithic, terrigenous facies (Facies B) is characterized by siliciclastic fine and very fine sediments with a calci-lithic component (Miocene calcareous clasts) mainly in medium and fine sands.

Facies C is characterized by a mixed bioclastic and siliciclastic muddy sand situated between the shoreface and the shallower limit of the meadow ($-2\text{ m}/-8\text{ m}$). Facies D consists of mixed bioclastic/siliciclastic gravelly sands and gravelly muds that are related to discontinuous meadow mainly *C. prolifera*, *C. nodosa* and *P. oceanica*. Facies E (biogenic gravelly sand) was sampled in the patches of residual uncolonized substrate occurring within the discontinuous meadow ('intermattes').

The distribution of the Facies F sediment (mixed bioclastic/siliciclastic sands and muds; Table 2) is situated between -15 and -20 m and between the shoreface and the shallower limit of inner shelf.

4.3. Hydrodynamics

Wave climate offshore of Giorgino beach has been reconstructed from the 30-year-long NOAA (National Oceanographic Atmospheric Administration) hindcast dataset (Chawla, Spindler, & Tolman, 2012). This dataset, developed using the Wave Watch III model, covers

Table 2. Sedimentological characteristics of sedimentary facies.

Sediment facies	Gravel %	Sand %	Mud %	Quartz + Feldspar %	Other minerals %	Lithoclasts %	Bioclasts %	Depositional environments
(A) Siliciclastic sands	1.4 ± 8.5	93.6 ± 10.8	5 ± 7.6	85.3 ± 9.6	2.9 ± 1.4	1.6 ± 9.4	10.2 ± 4.9	Shoreface sands (0–6 m)
(B) Calci-lithic	2.8 ± 3.2	96.0 ± 2.6	0.8 ± 1.5	32.3 ± 14.2	23.8 ± 27.0	20.5 ± 39.7	23.0 ± 32.4	Foreshore/shoreface (0–5 m)
(C) Mixed bioclastic and siliciclastic muddy sands	6 ± 13.7	72.1 ± 25.1	21.7 ± 26.1	70 ± 31.8	2.7 ± 2.0	0.1 ± 0.3	27.2 ± 33.1	Transition from shoreface to the upper limit of meadow (2–8 m)
(D) Mixed bioclastic/siliciclastic gravelly sands and gravelly muds	10 ± 14.7	48.5 ± 29.4	41.3 ± 35.2	72.9 ± 22.1	2.3 ± 2.2	2.6 ± 4.1	22.2 ± 23.5	Discontinuous meadow mainly <i>C. nodosa</i> , <i>C. prolifera</i> and <i>P. oceanica</i> (4–20 m)
(E) Biogenic gravelly sands	27.4 ± 26.1	65.3 ± 36.0	7.4 ± 10.0	28.5 ± 19.1	0 ± 0.0	16 ± 21.2	56 ± 39.6	Intermattes (5–15 m)
(F) Mixed bioclastic/siliciclastic sands and muds	2.7 ± 5.5	39.7 ± 40.7	57.6 ± 43.5	31.9 ± 15.1	13.3 ± 22.7	9.8 ± 9.2	24.9 ± 13.6	Inner shelf (15–20 m)

Table 3. Simulated wave cases.

Name	Hs (m)	Tp (s)	Direction (°)
N1	2.7	8.5	135
N2	1.6	6.7	157.5
N3	2.6	9.7	225

the period from 1979 to 2009 with a time resolution of 3 hours and a spatial resolution of 0.167° in the Mediterranean area. We extracted the data from the NOAA grid node located at 39.167° N and 9.167° E as representative incoming wave conditions for Giorgino – Villa D’Orri beach system. We retained only the wave data associated with the sectors that contribute with more than 5% of the total offshore wave energy. The SE sector is the most energetic sector with a contribution of 41% of the total energy. Moreover, significant energy contributions come from the SW (20%) and SSE (10%) directions. For each sector, wave height

data were fitted to a log-normal distribution (Castillo, Baquerizo, & Losada, 2005; Infantes, Terrados, Orfila, Canellas, & Alvarez-Ellacuria, 2009) to identify the significant wave height H_{s12} that is exceeded for 12 hours per year.

With the main aim of understanding the general coastal circulation of the studied area, hydrodynamics driven by waves coming from SE, SSE and SW have been simulated with the Delft3D modeling package (see Table 3 showing H_{s12} and the other incident wave parameters). We used a multi-grid approach in which the incoming wave conditions are imposed on the offshore boundary of the coarser grid. The wave dynamics and the main currents were computed, respectively, with the WAVE and the FLOW modules of Delft3D over the finer grid that extends over the shallow area.

Figure 2(A,B) shows the computed significant wave height (A) and main currents (B) associated with case

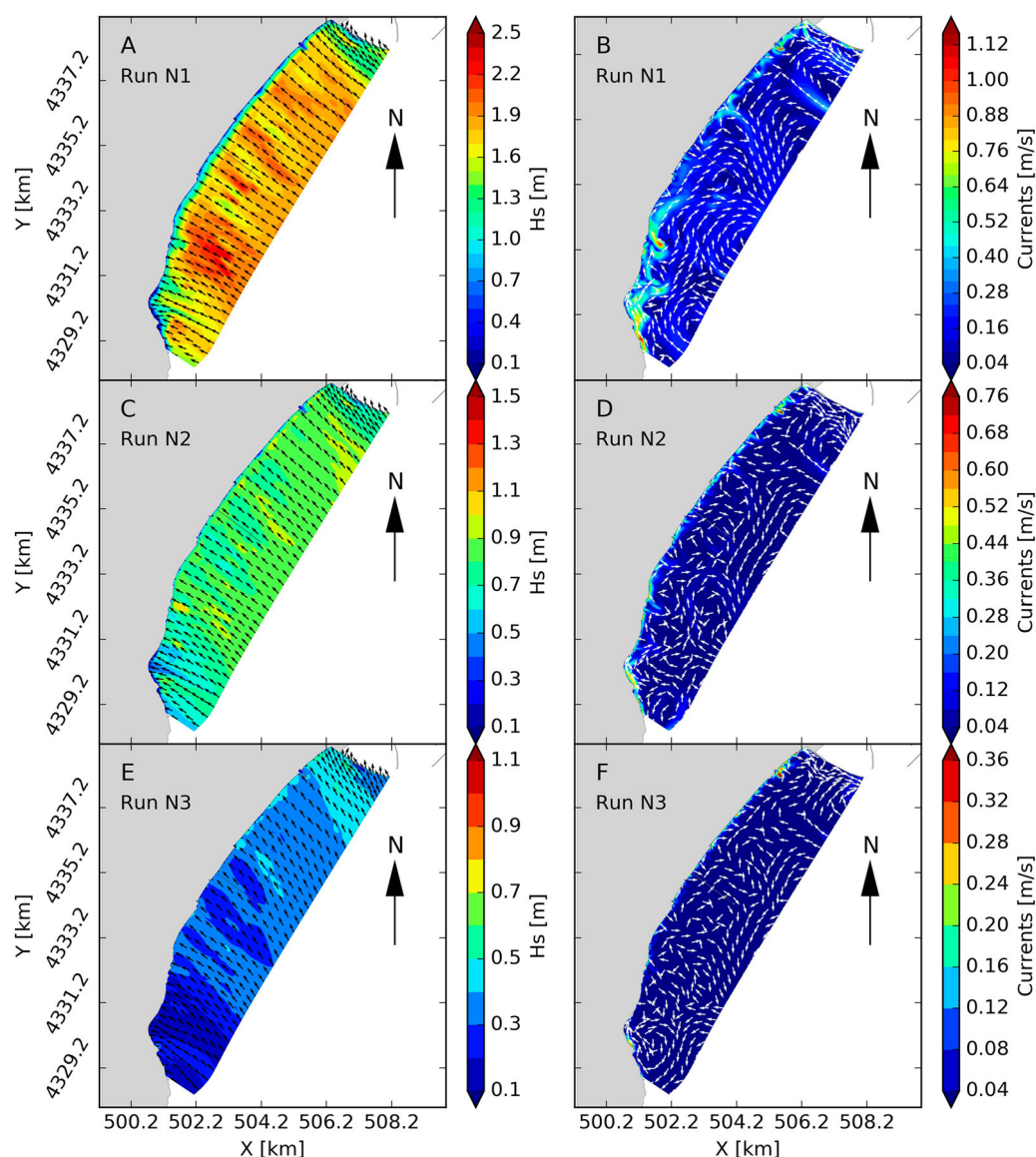


Figure 2. Significant wave height (A) and main induced coastal currents (B) associated with case N1 (waves from SE). Significant wave height (C) and main induced coastal currents (D) associated with case N2 (waves from SSE). Significant wave height (E) and main induced coastal currents (F) associated with case N3 (waves from SW).

N1. A northward longshore current flows intensely (0.8 m/s) in the Villa D'Orri sector, then it continues with a magnitude on the order of 0.5 m/s along the entire coastline. The longshore current direction inverts just locally in the central sector of Giorgino beach just N of the Syndial pier, where a rip current is fed by two opposing longshore currents. In the northernmost part of the beach a rip current flows along the port pier.

In the scenario N2 (Figure 2(C,D)), the coastal circulation patterns are similar to those of the previous case with the main difference that, due to the moderate incoming energy, wave-induced currents are weak and limited to shallow waters.

Nearshore hydrodynamics forced by a swell from SW (case N3) are plotted in Figure 2(E,F). Waves approach the shoreline with a large angle of incidence with a considerable wave height reduction associated with pronounced refraction processes. The weak northeast-oriented longshore current that develops in shallow waters feeds a weak rip current that flows along the pier. In general terms, simulations suggest that longshore currents are mainly northeast oriented along Giorgino beach. In particular, the beach width discontinuities observed NE of the lagoon mouths in sector 5, seem to confirm the predominant northeastward direction of currents and associated sediment transport fluxes. Finally, all the simulated wave scenarios show rip currents flowing in the central sector of Giorgino beach and along the harbour pier, whose intensity depends on the energy of the incoming waves.

4.4. Human impact

Map 4 shows the six sectors where human impact may influence the beach morphology and dynamics.

The first sector is delimited in the SW by a large industrial complex (built in the 1960s) with two piers for the petrochemical/oil industry that accommodate mooring for ships. In this sector, the human impact is mainly related to launching and beaching small boats for fishing. The backbeach is characterized by woody and masonry structures.

The second sector is the most pristine of the whole area. The main human impact is linked to recreational activities (like kitesurf) and beach cleaning. Additional impacts are the pedestrian and vehicular transit on foredunes that contributes to vegetation degradation and triggers deflation processes.

The third sector is affected by the highest residential and touristic pressures which limit landward the beach amplitude. This urban development has led to the significant modification of the fluvial catchment system in the alluvial plain that has caused a negative change in the terrigenous sedimentary input to the beach. Groynes were built in 2014 in order to protect the urban area, the river delta and the shoreline from erosion.

The fourth sector is mainly impacted by beach cleaning, bulldozing and recreational activities. The sandy backshore, subjected to nourishment work, is bordered by small embryo dunes that in some parts are alternated with artificial foredunes.

The fifth sector (Map 4), about 4 km long, is characterized by a complex system of four lagoonal mouths which are periodically dredged and sediments are transported faraway the beach system. Close to the most southwestern mouth, a beach area has been filled since the end of the nineteenth century in order to facilitate the boarding of materials from the mining areas of SW Sardinia. A pier (Syndial) was built in the 1970s for supporting the industrial zone operations.

The sixth sector (about 3000 m long) includes the Canal Harbour, built in 1970, that extends to 2500 m, with 1600 m of the quay, offering berths for transshipment and ships cargo. The seabed in front of the Canal Harbour piers is repeatedly subject to dredging and it is characterized by muddy sediment and turbidity. Close to the Canal Harbour, the mouth of an artificial canal from saltworks was built between 1970 and 1999. In this sector, a road limits the beach amplitude landward.

5. Discussion

In the last century, the surrounding areas of the western side of Cagliari Gulf have been changed by several modifications (Table 1) linked to the increase of urbanization in a system where waves and littoral currents are the dominant coastal processes for transport and deposition of sediments. Firstly, this significant urbanization has caused the narrowing and hardening of the studied beaches. The backshore appears to be mostly affected by processes of erosion that caused the reduction of beach and dune system widths. In addition, the construction of transversal and oblique groynes and the hardening of lagoonal mouths modified the beach morphology causing its segmentation in both along- and cross-shore directions. The rigid coastal structures currently tend to reflect rather than dissipate wave energy thus affecting beach morphology. Secondly, the construction of the Canal Harbour diminished the beach extent by 2.5 km and modified the water circulation producing an asymmetric sediment accumulation.

In contrast with previous studies carried out on different beaches (De Muro et al., 2016; De Muro, Porta, Passarella, & Ibba, 2017), no explicit link between the coastal circulation and the set-up of the upper limit of the *P. oceanica* meadow has been recognized in the present work. This fact is likely to be related to the intense human activity (e.g. dragging, ship anchoring, pollution, solid wastes related to industrial activity, etc.) that affects the shoreface environment. This is likely to yield a high turbidity level of the marine superficial waters with a consequent

negative impact on *Posidonia oceanica* habitats (loss of biodiversity, decreasing in abundance of sensitive species) causing fragmentation and retreat of the meadow's upper limit. Consequently, between -4 and -20 m, a wide area of degraded and discontinuous *P. oceanica* and dead meadow in front of the study beach has been recognized. Reflecting the poor state of the *Posidonia* upper limit, the presence of *C. prolifera* (with which the *Posidonia* competes for the substrate) has been documented both within the shoreface and the banquette during data collection. The poor ecological status of the *P. oceanica* upper limit has been also revealed in the Cagliari Gulf by low values of biodiversity of the benthic foraminiferal assemblages and high abundance of opportunistic and stress-tolerant foraminiferal species. This observation agrees with most of the studies carried out in highly impacted coastal areas of Sardinia. For instance, the decline in foraminiferal biodiversity was found at Portoscuso (Cherchi et al., 2009), La Maddalena (Salvi et al., 2015) and Porto Torres (Buosi et al., 2013b), in southern and northern Sardinia, respectively. The absence of epiphytic species that live attached to *P. oceanica* leaves is an additional marker of degraded conditions of the meadow (Vidović, Čoso- vić, Juračić, & Petricoli, 2009). The *P. oceanica* plays a key role in coastal management as agent for erosion protection (De Muro, Batzella, Kalb, & Pusceddu, 2008; Simeone, De Muro, & De Falco, 2013; Gómez-Pujol, Orfila, Álvarez-Ellacuría, Terrados, & Tintoré, 2013), fish nursery and water oxygenation (Boudour- esque, Bernard, Pergent, Shili, & Verlaque, 2009, 2012; Vacchi et al., 2017). It is known that seagrass meadow may attenuate hydrodynamic forces, may increase the sediment retention and may reduce sediment resuspension (De Muro, Kalb, Ibba, Ferraro, & Ferrara, 2010; Tecchiato, Buosi, Ibba, Ryan, & De Muro, 2016). Thus, an adequate monitoring of its ecological status and a sustainable coastal development should be assured by local administration to preserve the meadow and to secure its important role in maintaining a healthy marine environment.

6. Conclusions

Our study presents a map showing static and dynamic coastal processes deriving from the interaction between morphodynamics, eco-geomorphological setting, sedimentary facies and human interventions. Three main benthic habitats and six sedimentary facies were identified in the studied area. The benthic foraminiferal assemblages showed a poor and bad ecological status in samples located in the discontinuous meadow. The wave climate analysis shows that Giorgino beach is mainly exposed to wave energy from the southern quadrants, with a dominance of the SE sector. Hydrodynamic simulations suggest that incoming waves

mainly drive longshore NE-oriented currents and rip currents that tend to be intense in the proximity of the harbour pier.

Six sectors, characterized by different anthropic pressure and use, have been recognized in the coastal zone. Data reported in the [Main Map](#) serve to create a comprehensive geomorphological and sedimentological benchmark for the long-term planning and management of this urbanized coastal system.

Software

Reson PDS2000 was used for the acquisition of the bathymetric data. The textural data were obtained with the Gradistat software (Blott & Pye, 2001). The sample data and the SSS data were processed using Autodesk Map 3D to obtain the grain-size distribution and to identify the main habitat. QGIS software was used to create a georeferenced topographic-bathymetric base map and to depict the granulometric distribution of the sediment. The final map was produced using Adobe Illustrator CS5. Google Earth GIS was used for calculate distances and angles of wave exposure and fetch of the study area.

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Map 3



Sedimentary facies, ecological status and bathymetric profiles

Facies

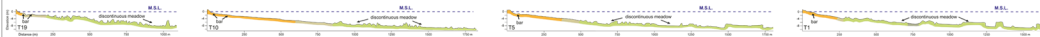
- A** Siliclastic sands: facies composed of shoreface sands, mainly siliclastic
- B** Sands and gravelly sands: facies composed of calc-illitic and terrigenous component (Cape S. Elio calc-illitic facies, Lenzi et al., 2005)
- C** Mixed biotactic and siliclastic sandy-muddy sediment: facies composed of biogenic/biotactic and siliclastic sand and mud (transition from the shoreface to the seagrass meadow upper limit)
- D** Mixed biotactic/siliclastic gravelly sands and gravelly muds: facies composed of biogenic/biotactic and siliclastic gravelly sands and gravelly muds of discontinuous seagrass meadow mainly "Cymodocea nodosa", "Caulerpa prolifera" and "Posidonia oceanica"
- E** Biogenic gravelly sands: facies composed of biogenic gravelly sands linked to the seagrass meadow (intermites)
- F** Mixed biotactic/siliclastic sands and muds: facies composed of fine sands and muds mainly siliclastic of inner shelf

Other features

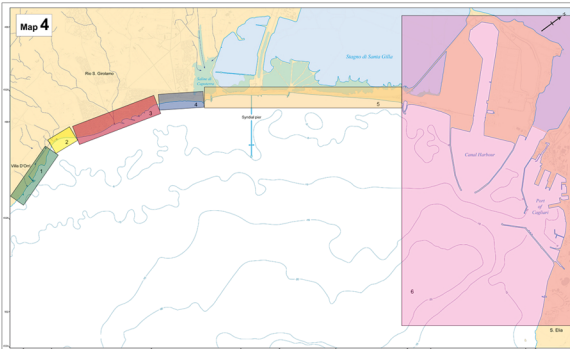
- G** Seagrass meadow mainly "Posidonia oceanica"
- H** Dredged areas industrial harbour and nourishment sediment
- Shoreline
- Transect

Ecological status

- Moderate
- Poor
- Bad



Map 4



Human impact and use

- 1** Fishing activities: woody and masonry structures
- 2** Recreational activities and beach cleaning: pedestrian and vehicular transit on foredune
- 3** Extensive residential and touristic pressure
- 4** Beach cleaning, bulldozing, nourishment and recreational activities
- 5** Dredging and hardening of lagoonal routes
- 6** Maritime traffic and port activities
- Depth line (5 m interval)
- Shoreline