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Much damage for little advantage: Field studies and morphodynamic modelling highlight the environmental impact of an apparently minor coastal mismanagement

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ABSTRACT

While coastal management activities have long been known to exert a strong influence on the health of marine ecosystems, neither scientists nor administrators have realized that small interventions may lead to disproportionately larger impacts. This study investigated the broad and long-lasting environmental consequences of the construction of an ill-planned, although small (only 12 m long) jetty for pleasure crafts on the hydrodynamic conditions and on the meadow of the seagrass *Posidonia oceanica* of an embayed cove in the Ligurian Sea (NW Mediterranean). There, *P. oceanica* used to develop on a high (>1.5 m) matte (a lignified terrace causing seafloor elevation) in which the leaves reach the surface and form a compact natural barrier to waves in front of the beach. Such a so-called 'fringing reef' of *P. oceanica* is today recognized of high ecological value and specific conservation efforts are required. The construction of the jetty implied the cutting of the matte, which directly destroyed part of the fringing reef. In addition, meadow mapping and sedimentological analyses coupled with morphodynamic modelling showed that the ecosystem of the whole cove had been greatly altered by the jetty. We used the geometric planform approach, a proper tool in the study of headland-controlled embayment, both to characterise the present situation of Prelo cove and to simulate the original one, before the jetty was built. In the long term, such a small jetty completely altered the configuration and the hydrodynamic conditions of the whole cove, splitting the original pocket beach into two smaller ones and creating strong rip-currents flowing seaward along the jetty. These rip-currents enhanced erosion of residual shallow portions of the meadow and further modified the sedimentary fluxes in shallow waters. A century after the construction of the jetty, an irreversible environmental damage has occurred, as the slow growing rate of *P. oceanica* implies that the high matte terrace and the fringing reef will hardly form again, even after the removal of the jetty. The lesson learnt from this study is that even such small, and therefore reputed intrinsically 'innocent', interventions on the coastal zone require accurate planning based on interdisciplinary studies to understand and respect the delicate interplay among morphological, hydrodynamic and ecological components.

1. Introduction

In the last century, the extensive proliferation of urban structures on coastal areas has caused radical changes in marine ecosystems. This is especially true for the Mediterranean Sea, where more than two-thirds of the coastline is now urbanized (Montefalcone et al., 2009), a figure that is expected to rise substantially in the future (Bianchi et al., in press). While coastal management activities have long been known to degrade the health of marine ecosystems, neither scientists nor administrators have realized that small interventions may lead to disproportionately great impacts. Amplified effects of comparatively small human pressures, however, should be expected when coastal interventions affect marine habitats shaped by long-lived 'structural' species, such as corals, kelps and seagrass, that act as 'ecosystem engineers' (Erwin, 2008).

Seagrasses are highly sensitive to environmental alterations and the loss of large vegetated areas is today a worldwide concern (Green and Short, 2003; Waycott et al., 2009). The proliferation of coastal structures (i.e. jetties, harbours, embankments, etc.) during

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the last century modified the morphology of the coastline and caused changes in hydrodynamic conditions of coastal zones (Tigny et al., 2007; Cabaço et al., 2008). The health of seagrass is now understood to be directly influenced by land reclamation activities (Benoit and Comeau, 2005; Shochat et al., 2006), as well as by consequent changes in hydrodynamic conditions (Mokhtar and Aziz, 2003; Vacchi et al., 2010).

Seagrass meadows are widely recognized as key marine ecosystems (Hemminga and Duarte, 2000), providing habitat and services for the coastal zone and shaping its features. Seagrass canopy acts as an efficient sediment trap that enhances settlement of particles and prevents their re-suspension (Erftemeijer and Koch, 2001; van Katwijk et al., 2010), attenuates wave energy (Jeudy De Grissac, 1984; Duarte, 2004), and contributes to shoreline stabilisation (Short et al., 2007). The complex root/rhizome system of seagrass, which binds sediments, also prevents erosion of the seafloor (Fonseca et al., 1982; Gacia et al., 2003).

Posidonia oceanica (L.) Delile, the most important and abundant seagrass in the Mediterranean Sea, has the exclusive capacity, among seagrasses, to build a high (up to more than 6 m) and lignified structure, known as 'matte' (Boudouresque et al., 2006), resulting from the horizontal and vertical growth of rhizomes combined with dead rhizomes, roots and particles of sediment. The slow and constant vertical growth of the matte, estimated at about 1 cm per year (Caye, 1982), elevates the seafloor (De Falco et al., 2003) and, in sheltered areas, enables the meadow to approach the water surface, developing a so-called 'fringing reef'—a partially emerged structure in which the leaves of *P. oceanica* reach the surface and form a dense and compact natural barrier to waves (Boudouresque et al., 1985). Fringing reefs of *P. oceanica* have been defined as natural sites with high ecological value that require specific conservation efforts (Relini, 2000; Borg et al., 2005).

Although *P. oceanica* meadows are listed as priority habitats in Annex I of the EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Flora and Fauna (EEC, 1992), they are experiencing a large-scale decline in many areas of the Mediterranean Sea, due to both natural and anthropogenic disturbances (Marbà et al., 1996; Boudouresque et al., 2009; Montefalcone et al., 2010a, in press).

In this paper we investigate the state of a *P. oceanica* meadow in a small cove in the Ligurian Sea (NW Mediterranean), where part of the existing fringing reef was destroyed at the beginning of the 20th century to build a small (12 m long) jetty for pleasure craft. We hypothesized that the present status of the meadow is not only the legacy of the direct impact of this construction, but also the long-term result of altered hydrodynamic conditions caused by the jetty's presence in the cove, especially sediment transport caused by the presence of the jetty, which indirectly enhanced much greater regression of the meadow than the size of the jetty had led planners to predict.

In addition to conducting field studies on seagrass and sediment distribution, we assessed the hydrodynamic conditions of the Prelo cove through geometric planform analysis (Bowman et al., 2009), a synthetic and comprehensive modelling approach to studying the morphodynamics of embayed coasts, understanding beach and nearshore morphological changes and describing patterns of rip-currents constrained by an embayed geometry (Silvester and Hsu, 1993; Short, 1999; Klein and Menezes, 2001). In order to characterise the present hydrodynamic conditions of Prelo cove, we defined its geometric planform configuration (i.e. orientation, sheltering, degree of embayment), and we then simulated its original geometric configuration to describe the hypothetical hydrodynamic conditions that prevailed before the construction of the jetty. Several studies correlated the state of *P. oceanica* meadows with sedimentological features (Gacia et al., 1999; Cavazza et al., 2000; De Falco et al., 2000, 2008; Gacia and Duarte, 2001), but few took into account coastal dynamics (Basterretxea et al., 2004; Koch et al., 2006; Infantes et al., 2009; Vacchi et al., 2010).

2. Material and methods

2.1. Study area

Prelo is a typical Ligurian embayed cove located close to Genoa (Italy, NW Mediterranean), with a rocky coastline and a natural pocket beach between rocky headlands (Fig. 1). In the central part of the beach a small jetty (12 m long) was built at the beginning of the 20th century to create a space for pleasure craft (Fig. 2). The beach is characterised by gravel of local origin, as no sediment input due to water courses occurs in the cove. The cove is sheltered from waves coming from SW and S by its specific headland geometry and it is moderately protected against the dominant waves coming from SE (having a direction of 85° N). The dominant waves are only slightly attenuated by diffraction approaching the shoreline. A rocky substratum characterises the seafloor of Prelo cove, which is subjected to a tectonic control. Distinct sets of faults, oriented E–W and NW–SE and linked to a Riedel system (Riedel, 1929), caused dislocations in the seafloor (Corsi B., unpublished work) that generated a depression in the central part of the cove at about 8 m depth (Figs. 1 and 4).

2.2. Field activities

The *P. oceanica* meadow of Prelo cove was investigated by scuba diving along 11 underwater transects randomly positioned perpendicular to the coastline (Fig. 1). Dives were carried out starting from the lower limit of the meadow toward its upper limit; dead matte areas occurring beyond the present extent of living *P. oceanica* were also considered. Transects (from 90 to 250 m long) were visualized by a nylon line laid on the seafloor and marked every 5 m. The starting and the ending points of each transect were

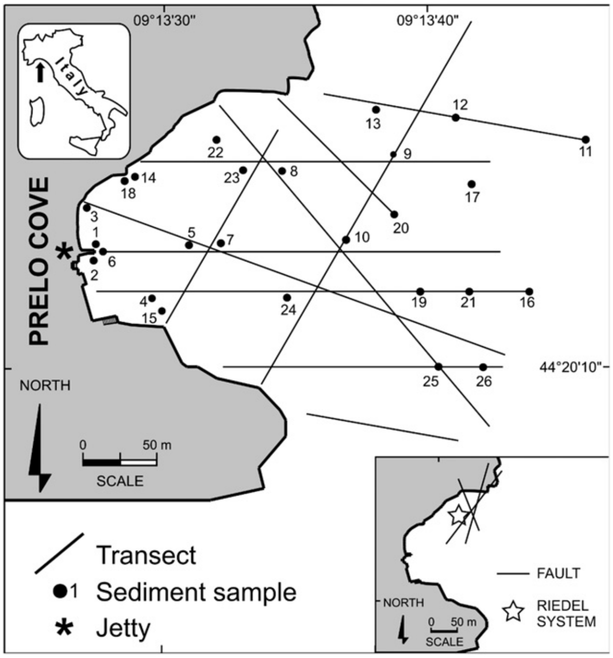

Fig. 1. Study area with underwater transects and sediment samples. Faults, the Riedel system and the location of the jetty are also indicated.

Fig. 2. The jetty built in Prelo cove at the beginning of the 20th century for pleasure crafts.

recorded using a GPS in RTK mode. Every 5 m along each transect, depth was recorded and cover of living *P. oceanica* and/or dead matte (expressed as the percentage of seafloor occupancy) were visually estimated by two divers, swimming approximately 2 m above the marked line, over a surface of about 25 m^2 (Montefalcone, 2009). The occurrence of sandy channels and sandy clearings was also recorded. A total of 26 sediment samples (Fig. 1) was collected from the uppermost sediment layer (0–5 cm) of sandy channels, sandy clearings and dead matte areas, using a hand-held corer. The position of the sample stations was recorded using a GPS in RTK mode.

2.3. Data analysis

Cover values of living *P. oceanica* were grouped in three classes as defined by Lasagna et al. (2006a): single shoots ($<$15%), low cover (from 15% to 65%) and high cover ($>$65%). Types and status of meadow limits were recognized according to Montefalcone (2009), who distinguishes several natural (healthy) and regressed morphologies. A thematic map of *P. oceanica* meadow morphology, including depth contours obtained by triangular interpolation, was elaborated at the scale of 1:1000, but a smaller version is reproduced in the present paper (Fig. 4a). Sediments from each sample were classified either as finer (diameter $<$ 63 μm, clay and silt fraction) or coarser (diameter $>$ 63 μm, sand, gravel and pebble fraction), according to Wentworth (1922). The size of finer sediments was measured using the Micromeritics SediGraph 5100 and coarser sediments using the dry sieving method. For each sample, mean grain size (Mz), sorting (σ) and skewness (Sk) were assessed according to Folk (1966). These three sedimentological parameters were normalized and analysed using nMDS (non-metric multidimensional scaling) and SIMPROF (similarity profile permutation analysis) allowed identifying significant groups (Clarke and Gorley, 2006).

The directions of sediment transport within Prelo cove were assessed using the methodology proposed by Gao and Collins (1992), which is based on the assumption that spatial changes in surface sediment can yield the residual transport paths. Two cases are generally representative of sediment transport from a site 1 to a site 2:

(1) $\sigma_1 > \sigma_2$, $Mz_1 < Mz_2$ and $Sk_1 > Sk_2$ (i.e. sediment becomes better sorted, finer, and more negatively skewed along the pathway);
(2) $\sigma_1 > \sigma_2$, $Mz_1 > Mz_2$ and $Sk_1 < Sk_2$ (i.e. sediment becomes better sorted, coarser, and more positively skewed along the pathway).

Grain Size Trend Analysis (Gao, 1996) was used to calculate the directions followed by sediments (visualized on map as transport vectors), comparing the sedimentological parameters between neighbouring pairs of sampling sites within the critical distance (defined from the sampling grid, 25 m in our study). Transport

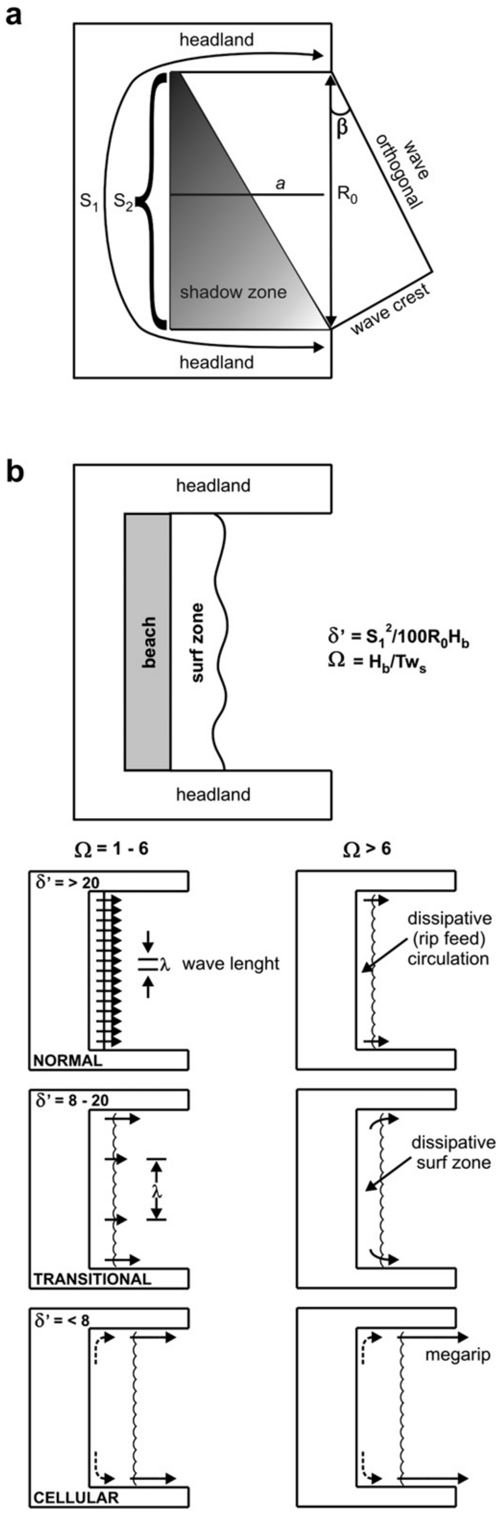

Fig. 3. a) Schematic representation of a coastal embayment with the planform parameters; b) Different situations of surf zone circulation based on the embayment scaling index (δ') and the Ω index. From Short (1999) modified.

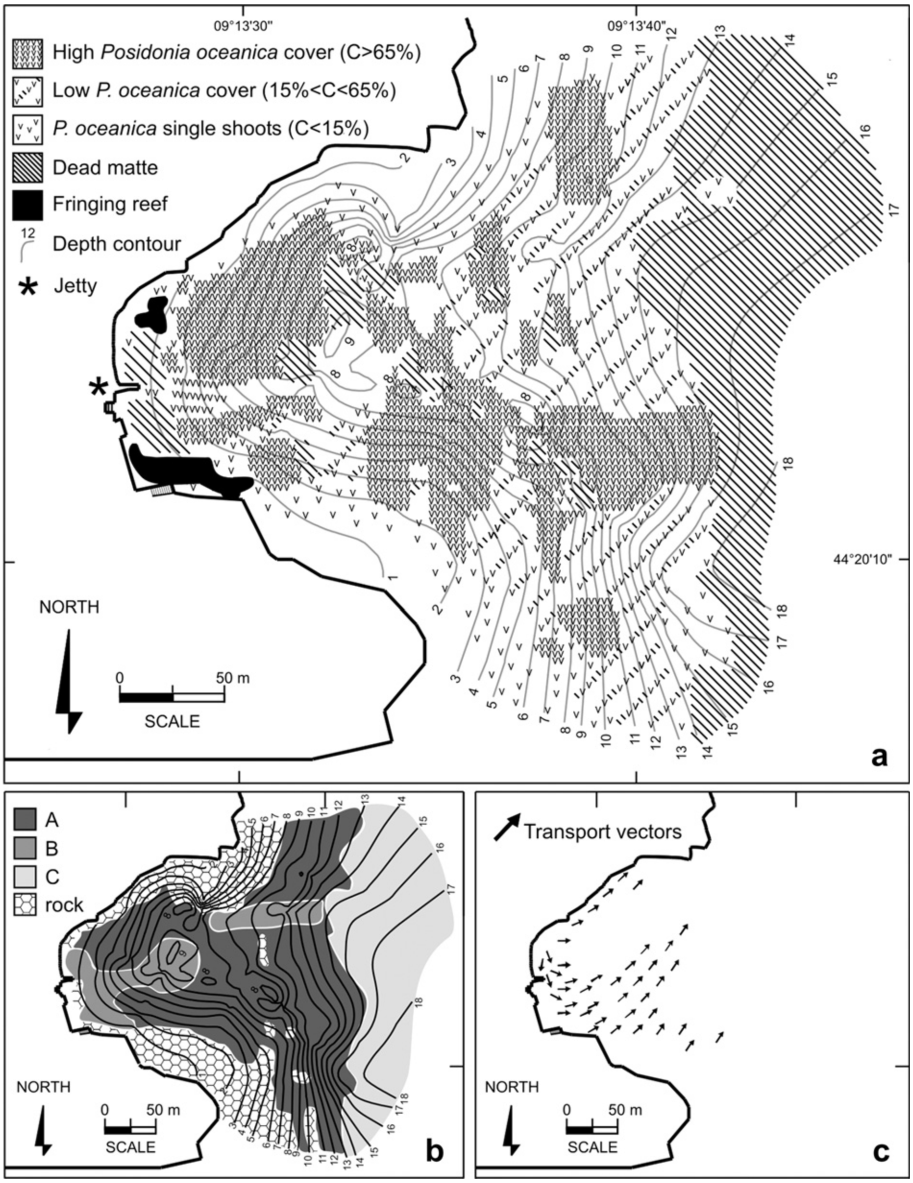

Fig. 4. a) Map of the *Posidonia oceanica* meadow morphology; b) Map of the sedimentological features of Prelo cove (A = very coarse sand; B = coarse and medium sand; C = fine and very fine sand); c) Map of the sediment transport vectors.

vectors were interpolated in a regular grid of 1080 points by kriging (Stein, 1999). Two thematic maps showing sedimentological features and sediment transport vectors in the study area were elaborated at the original scale of 1:1000, but two smaller versions are reproduced in the present paper (see Fig. 4b, c).

2.4. Morphodynamic modelling

Geometric planform analysis (Bowman et al., 2009) was used to define the planform characteristics of the Prelo cove in two different situations: (1) the present situation, where the jetty is viewed as an artificial headland that divides the embayed cove into two smaller sub-coves (the northern and the southern sub-coves) and the pocket beach in two smaller artificial pocket beaches; (2) the simulated original situation of Prelo before the jetty was built, with the whole embayed cove and pocket beach still occurring. For both situations (i.e. the present and the simulated), the following two-dimensional planform parameters were measured from the topographic map of Prelo, provided by the Liguria Region in scale 1:5000 (Fig. 3a):

1. headland spacing (R_0), i.e. the length and orientation of the cove (or of the sub-cove), measured from its northern to southern margins;
2. bay indentation (a), measured from R_0 to the most pronounced retreat of the cove (or sub-cove);
3. length of the embayed shoreline (S_1);
4. length of the embayed beach (S_2).

From the four planform parameters above, three planform indices were computed for both situations:

1. a/R_0 to characterise the degree of embayment of the cove (Silvester and Hsu, 1993);

(2) S_1/R_0 to measure the indentation of the cove (Spagnolo et al., 2008), later classified according to the five categories suggested by Bowman et al. (2009);
(3) S_2/S_1 to measure the magnitude of the sediment fill in the embayment (Bowman et al., 2009).

In order to describe the surf zone circulation in both situations, the most significant annual wave height offshore (H_0) and the wave period (T) were obtained from MEDATLAS (2004). The diffracted wave (H_d) was obtained by correcting H_0 with respect to diffraction using the formula

$$H_d = H_0/\mathit{sen}ß,$$

where β is the angle between the wave orthogonal and R_0 (Fig. 3a). Similarly, to compute the incident breaking wave height (H_b) we applied the formula

$$H_b = \sqrt{\left[H_d^2 \cdot (R_0/S_1)\right]},$$

neglecting shoaling and bed friction (CERC, 1984). Finally, planform and hydrodynamic parameters were combined to measure two morphodynamic indices for both the present situation with two artificial embayed beaches and the simulated original whole beach (Fig. 3b):

(1) embayment scaling (δ'), which relates the length of the embayed shoreline (S_1) that adsorb energy (at a typical surf zone gradient of 0.01) to the incident breaking wave height (H_b) and the bay exposure (R_0) and is computed by the formula (Short, 1999):

$$\delta' = S_1^2/100\ R_0 H_b;$$

(2) Ω index, which relates the incident breaking wave height (H_b) to the sediment fall velocity W_s (CERC, 1984), and is computed by the formula:

$$\Omega = H_b/TW_s$$

According to Short (1999), the values of δ' and Ω classify the surf zone circulation as normal, transitional or cellular (Fig. 3b). Normal circulation occurs when weak backwashes flow seaward and are equally distributed along the whole embayed beach without condensed flows. Transitional circulation occurs when some weak and condensed backwashes flow seaward against each margin, but still maintain a normal circulation away from the margins within the embayment. Cellular circulation occurs when the topography dominates the surf zone circulation: a longshore flow dominates within the embayment, with strong seaward-flowing megarips occurring at one or both margins of the embayment.

3. Results

3.1. Meadow morphology

The *P. oceanica* meadow developed, although discontinuously, from less than 0.5 m to around 16 m depth, occupying about 5.3 ha in total (Fig. 4a). However, in less than half that extent the cover of living plant was high (>65%), the rest being characterised by low cover or even single shoots (<15%). The meadow was frequently interrupted by dead matte areas and by sandy clearings at any depth. The cut of the matte for the construction of the small jetty was still clearly recognizable, with exposed edges more than 1.5 m high. Two residual portions of the fringing reef still occurred at the two sides of the jetty: the northern portion occupied 0.03 ha, the southern 0.1 ha; both exhibited extremely high cover (near 100%). At the immediate sides of the jetty, 0.15 ha of dead matte areas were present. A small sandy clearing in front of the jetty extended seaward as a sandy channel, which in turn widened at about 8 m depth into a larger (about 0.18 ha) sandy clearing in correspondence with the central tectonic depression. The lower limit of the meadow reached its maximum depth at 15–17 m and was a regressive shaded limit for most of its extent, a regressive limit with residual patches of living *P. oceanica* being recognizable locally in the northern portion of the meadow and a sharp regressive limit in the central portion. Dead matte areas beyond the present lower limit occupied 1.7 ha, and extended seaward for more than 100 m in the northern portion of the meadow and for about 20 m in the southern portion, to reach 18 m depth.

3.2. Sedimentological features

Sediments in Prelo cove were mainly constituted of sand with different textures (Fig. 4b). SIMPROF identified three distinct groups ($p < 0.05$), easily recognized in the nMDS plane (Fig. 5): group A corresponded to very coarse and poorly sorted sand, with a symmetric or negatively skewed distribution; group B to coarse and medium moderately sorted sand, with a symmetric or negatively skewed distribution; group C to fine and very fine poorly sorted sand, with a positively skewed distribution. Sediments belonging to group A were found at the two sides of the cove, between the coastline and the upper limit of the meadow, and in the deepest portions of the meadow. Sediments belonging to group B were found all around the jetty, in the sandy channel and in the large sandy clearing on the tectonic depression. Sediments of group C were found in dead matte areas beyond the present lower limit of the meadow (Fig. 4b).

The map of the sediment transport vectors showed: 1) prevalence of sediment transport parallel to the coastline (i.e. longshore currents) along the northern side of the cove; 2) sediment transport orthogonal to the coastline (i.e. rip-currents) in correspondence with the jetty; 3) a backwash flow of sediments directed seaward due to reflection against the rocky coast in the southern side of the cove (Fig. 4c).

3.3. Morphodynamic features

Most values of hydrodynamic and planform parameters and indices calculated for the northern and the southern artificial

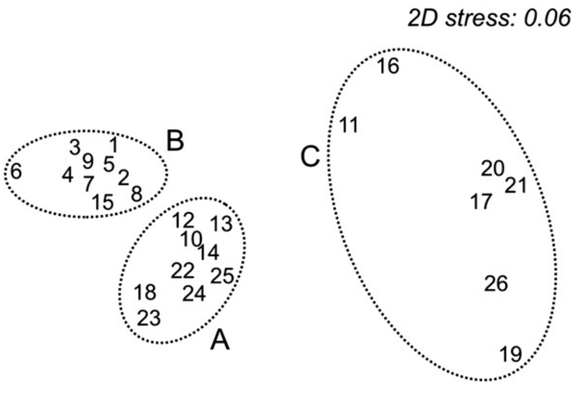

Fig. 5. nMDS ordination of sedimentological parameters (Mz, σ_1, Sk_1). Dotted lines indicate significant groups ($p < 0.05$) as resulting from the similarity profile permutation analysis (SIMPROF).

Table 1
Values of hydrodynamic and planform parameters and indices measured for the whole embayed cove (simulated original situation) and for the northern and the southern artificial embayed sub-coves (present situation).

	R_0 (m)	a (m)	S_1 (m)	S_2 (m)	a/R_0	S_1/R_0	S_2/S_1	H_0 (m)	H_d (m)	T (sec)	W_s (m s^{-1})	H_b (m)	δ'	Ω
Whole	244	181	500	98	0.74	2.05	0.2	1.5	1.2	5	0.08	0.8	12.5	2.0
North	57	20	86	45	0.35	1.51	0.5	1.5	0.8	5	0.08	0.6	2.1	1.4
South	48	15	89	53	0.31	1.85	0.6	1.5	0.3	5	0.02	0.2	8.3	1.9

pocket beaches (i.e. the present situation) and for the whole pocket beach (i.e. the simulated original situation) differ greatly (Table 1). The two indices a/R_0 and S_1/R_0 for the whole simulated beach define Prelo as an indented cove. The rocky headland in the southern side of the cove originates a wave shadow zone that includes the whole pocket beach (Figs. 3a and 6a) and, due to diffraction, reduces the wave height from $H_0 = 1.5$ to $H_b = 0.8$ (Table 1). The embayment scaling is high ($\delta' = 12.5$), whilst the Ω index is low ($\Omega = 2.0$), due to the coarser size of sediments. These two indices indicate a transitional surf zone circulation in the simulated situation (Fig. 6b).

The two artificial pocket beaches of Prelo, in the present situation, are both characterised by comparatively lower values of a/R_0 and S_1/R_0 and by higher values of S_2/S_1 than the beach in the simulated situation. The southern and northern artificial sub-coves are defined as low-indented; the former still lies inside the wave shadow zone and is characterised by a transitional surf zone circulation ($\delta' = 8.3$; $\Omega = 1.9$), the latter lies only partially within the wave shadow zone, so that a comparatively higher value of the diffracted waves (H_d) and lower values of the embayment scaling ($\delta' = 2.1$) and the Ω index ($\Omega = 1.4$) define a cellular surf zone circulation in this sub-cove (Fig. 6c).

4. Discussion

Both the present structure and health state of the *P. oceanica* meadow of Prelo showed influence by the morphological configuration and the hydrodynamic conditions of the cove, especially in shallow waters subjected to a surf zone circulation (Vacchi et al., 2010). Analysing the configuration of the headland-controlled embayment of Prelo with the geometric planform approach by Bowman et al. (2009), we were able to describe the morphodynamic behaviour of the pocket beach. Originally, in the simulated situation existing before the jetty construction when the whole pocket beach still occurred, the development of the *P. oceanica* meadow was likely to be mostly influenced by substratum nature (Lasagna et al., 2006b; Giovannetti et al., 2008) rather than by water movement. The low wave energy due to wind exposures, the shadow zone created by the southern rocky headland, and the weak backwashes flowing seaward as is typical of the transitional surf zone circulation (Short, 1999) allowed the shallow portions of the meadow to develop in a relatively sheltered area and to approach shore. In this situation the meadow had been able to build a high matte (>1.5 m high, needing more than one and half centuries to grow) that reached the water surface to form the fringing reef (Bianchi and Peirano, 1995).

Almost a century ago, Issel (1918) described the *P. oceanica* meadows of the area as a continuous 'green belt' along the coastline, with plants growing close to the shore and leaves reaching the water surface. Issel's description corresponds well to what should have been the situation of Prelo before the jetty was built: summing the present day extent of living *P. oceanica* with the extent of dead matte and sandy clearings, it is possible to provide an estimate of the original situation. It is thus more than likely that, before the cutting of the matte, the fringing reef was a continuous structure extending for about 0.4 ha along the whole pocket beach. Less than one third of it was found during the present study, the remainder having been directly cut away or indirectly reduced to exposed dead matte. Occurrence of dead matte areas around the jetty was the clearest evidence of the past existence of this fringing reef

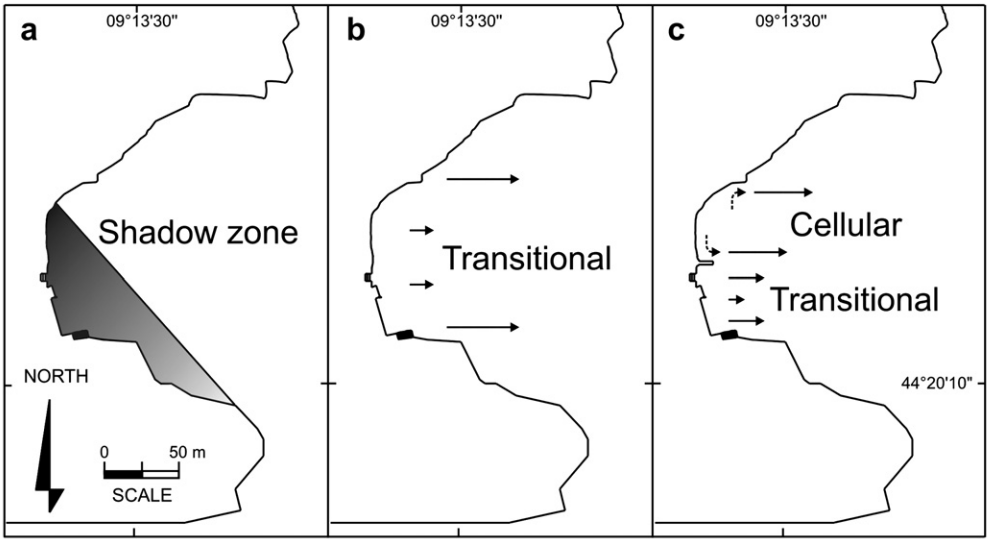

Fig. 6. a) The shadow zone originated by the southern headland in Prelo cove; b) Simulation of the transitional circulation with weak backwash flows occurring in the whole embayed cove before the jetty construction; c) Present situation of Prelo with a transitional circulation in the southern artificial sub-cove and a cellular circulation with occurrence of rip-currents in the northern artificial sub-coves.

(Leriche et al., 2004). Similarly, of the putative original meadow extent of 7.4 ha, one third was reduced to dead matte or unvegetated sand and one third to a sparse meadow.

The jetty built in the centre of the cove can be considered, in the geometric configuration of the embayment, as an artificial headland that divides the pocket beach into two smaller artificial embayed beaches. In addition to the direct impact of the jetty construction on the meadow health, the jetty caused alteration in the direction and intensity of the backwash flows compared to the original situation. In the southern artificial embayed beach, which still remains within the shadow zone, the circulation maintains transitional characteristics with weak backwashes flowing seaward along the two margins of the sub-cove, with the northern backwash flow concentrated along the jetty. In the northern artificial embayed beach, which lies partially out from the shadow zone and is characterised by a cellular circulation (Short, 1999), comparatively stronger backwash flows originated rip-currents that flowed seaward and were mainly concentrated along the jetty and along the northern margin of the sub-cove. The synergic action of the weak backwash flows in the southern sub-cove with the strong rip-current that flows along the jetty in the northern sub-cove, eroded continuously the exposed edges of the residual fringing reef. Today, only two small portions of the fringing reef showing erosive features (Colantoni et al., 1982) continue to exist at the two extremities of the cove.

As no sediment input occurs in Prelo cove, sediments are all of local origin and their distribution within the cove is the result of the altered hydrodynamic conditions. A map of the sediment transport vectors (Gao and Collins, 1992) supported our hypothesis of the cellular circulation in correspondence with the jetty and the occurrence of strong rip-currents flowing seaward. Directions followed by sediments evidenced a preferential pathway toward the central area of the cove where a large sandy clearing was generated within the meadow and where the sediment deposition is favoured by the tectonic depression in the seafloor. Away from the pathways followed by rip-currents, most of the sediments found in the meadow were very coarse and poorly sorted, as usual for *P. oceanica* growing on matte (Colantoni et al., 1982). Deposition of finer fraction (clay and silt) in the deepest portions of the meadow and on dead matte areas occurring beyond the present lower limit of the meadow was the result of the weak wave energy that characterises this coastal area (MEDATLAS, 2004). *P. oceanica* does not tolerate a proportion of finer fraction over 9% (Koch, 2001): this threshold value was largely exceeded in correspondence with the lower limit of the meadow. As a consequence, the observed regression of the lower limit was likely to be due to deposition of the finest sediments that have already been shown to control the depth distribution of the meadow (Colantoni et al., 1982; Gacia and Duarte, 2001). The general increase in water turbidity caused by the industrial and urban coastal development occurred in Liguria during the 1960s (Peirano and Bianchi, 1997; Peirano et al., 2005; Montefalcone et al., 2009) might have been an additional factor.

In the early years of the 20th century, conservation of marine habitats was not a major concern. Replacement of large portions of the *P. oceanica* fringing reef of Prelo (only recently considered as a natural site with high ecological value) with a jetty for pleasure crafts was obviously seen as just a way to make the site more attractive and, therefore, as an advantage to improve its appeal to tourists. Nearly a century later, due to the intense use of the beach by bathers, the jetty lost its function because boat access is forbidden during the summer, thus the jetty is now virtually unused. However, the environmental damage of even such a small construction persists: the jetty altered the coastal hydrodynamic conditions of Prelo cove and caused irreversible loss of important natural habitats. Today, attention to the ecological impact of coastal mismanagement is greater, but there remains a dangerous tendency to consider as ‘innocent’ such small interventions. This study provides evidence that this is not the case.

Preservation of the *P. oceanica* meadow in Prelo cove is mandatory, not only to comply with the requirements of the EC Directive (EEC, 1992), but because it represents one of the few examples of meadow still showing a residual fringing reef in Liguria (Bianchi and Peirano, 1995; Diviacco and Coppo, 2006). Removal of the jetty, which today has completely lost its use, might restore the original hydrodynamic situation of Prelo cove. However, after regression of a *P. oceanica* meadow, recolonisation of lost areas, via seeds, vegetative fragments or marginal spread of the meadow is extremely slow and may require centuries (Boudouresque et al., 2009). Due to the very small resilience capacity of this ecosystem (Montefalcone et al., 2011), the natural recolonisation of dead matte areas is unlikely, and the natural re-growth of the ancient 1.5 m high matte of the fringing reef is more than unlikely. Prelo cove is comparatively far from other local sources of human disturbance and the main direct impact on the meadow health has been shown to be the one caused by pleasure-boat anchoring chain systems (Montefalcone et al., 2006, 2008), which increased the degree of habitat fragmentation (Montefalcone et al., 2010b).

Distinguishing between natural and human-induced effects on marine ecosystems is often difficult (Morri and Bianchi, 2001). However, coupling field studies with morphodynamic modelling based on the analysis of the planform configuration of headland-controlled bays proved effective in evaluating the extent to which the altered hydrodynamic conditions by coastal constructions may impact marine habitats. This study shows that even interventions on the coastal zone so small that they have long been considered harmless, require accurate planning based on interdisciplinary studies to understand and respect the delicate interplay among morphological, hydrodynamic and ecological components.

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