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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

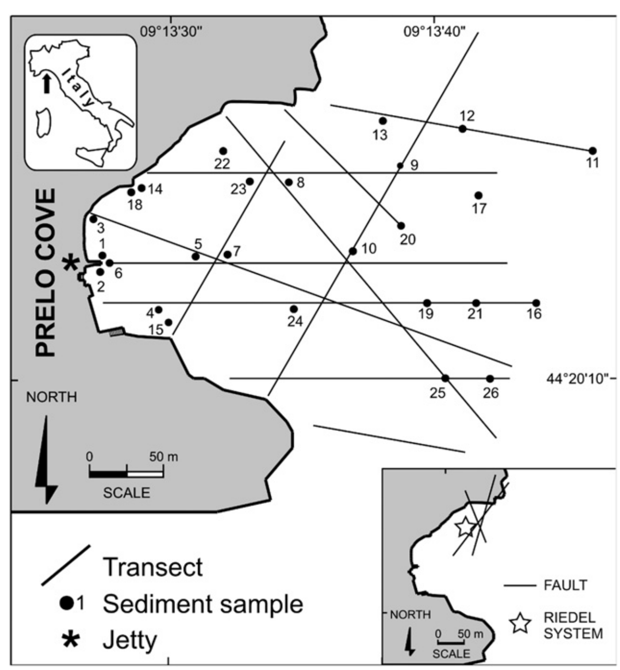

Fig. 1. Study area with underwater transects and sediment samples. Faults, the Riedel system and the location of the jetty are also indicated.