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Coastal Transformation and Marine Habitat Loss

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Abstract

Coastal areas are undergoing continuous transformation to sustain the increasing residential, commercial, and tourist activities. However, the proliferation of artificial infrastructures (i.e. marinas and breakwaters) may contribute to destroy and fragment marine natural habitats, to alter the connectivity among populations and, as a consequence, the natural seascape. In particular, the upper sub tidal rocky fringe, where the coastal transformations are more conspicuous, represents the natural habitat of dominant engineering algae, such as *Cystoseira* and *Sargassum*; some of them, because of their sensitivity to environmental variability, are considered biological elements of water quality.

The recent attempt to measure historical changes in macro algal diversity in the Gulf of Naples has highlighted a dramatic decrease of *Cystoseira* species in the upper sub littoral zones and at the same time the lack of information on their up to date extension. To verify the influence of coastal development on the decline of *Cystoseira* species in the Gulf, the percentage of natural/artificial coastal length has been estimated with Google Earth orto-photos. The results testified a correspondence: the higher was the *Cystoseira* spp. loss, the greater was the development of artificial urban infrastructures.

To follow the temporal dynamics of these shallow systems, a complete re-monitoring of the fucoid distribution along the Neapolitan coast has been planned. Up to now, the occurrence of these species has been mapped and digitalized in a qGIS database (scale 1:2,500) for the shallowest fringe of the island of Ischia. An ongoing homogenization of diversity at a medium scale has been recorded: *Cystoseira compressa* (the less sensitive species) is the widespread species; fragmented stands of *Cystoseira amentacea* (the most sensitive) still exist. Their distribution is limited to natural habitats slope more gently while the highest diversity has been reached in rocky pools. Occasional settlements were recorded on artificial structures when natural marine habitat was preserved in the surrounding area and the distance among the algal patches could not be a limiting factor in the spreading of the species. These preliminary data seem to suggest that a stronger collaboration between engineers and ecologists could favour a better coastal management in order to mitigate the impacts of artificial infrastructures on natural marine ecosystems and avoid the loss of biodiversity.

Introduction

Coastal areas represent only 10% of the earth's land surface yet more than 60% of the human population lives in these zones; forecasts for the next decades foresee a further increase, as urbanization is driving a movement in population towards the coast.

A wide range of services are provided by marine and coastal ecosystems, the continuity of which has to be managed and guaranteed against the human settlement, the increasing sea over-exploitation and the coastal transformation. However, the proliferation of harbours, marinas, and artificial barriers to protect beaches from erosion are introducing in the coastal environment new habitats that can contribute to fragment and segregate marine benthic populations, altering their natural connectivity, and at last, causing a loss of biodiversity. Habitat destruction is considered indeed the major threat to biodiversity worldwide (Pimm and Raven, 2000).

In the Mediterranean Sea, the brown algae belonging to the order Fucales (i.e. *Cystoseira* and *Sargassum* spp.) were the dominant, habitat-forming species of rocky shallow coasts, but in the last decades, they have experienced a dramatic decline in many countries (Thibaut et al., 2005) and most of them are now protected by international conventions (Thibaut et al., 2014). Based on their different sensitivity to anthropogenic disturbances, some species of the genus *Cystoseira* have recently been considered as biological elements of water quality (Ballesteros et al., 2007).

Among the Mediterranean countries, Italian coastal regions are considered the most densely urbanized and populated, with more than 800 km of their coasts altered by the presence of anthropogenic infrastructures (WWF, 2014). In particular in the Gulf of Naples (Campania, South Italy) comprises the greatest maritime station of the world, that is the 'Angioino' dock in the harbour of Naples, covering an area of 12,000m^2 (Flagella et al 2006), and the highest population density, largely exceeding 2,750 inh/Km^2 (on the island of Procida) and reaching exceptional densities, comparable to an Asian megalopolis (i.e. Portici: 12,000 inh/km^2) (Istat, 2013). However, due to its artistic and archaeological interests and natural beauty, this area represents one of the

favourite destinations for tourists: an example is given by the Ischia island (the largest among phlegrean islands), with about 4 million travellers per year (http://www.ischiamarket.com/informazioni-ischia.php).

To evaluate the effects of anthropic pressures on marine benthic systems in the Gulf of Naples, a long term analysis has recently been performed comparing historical-present biological data (1878-2013). Results for the macro algal communities (Buia et al., 2013) have highlighted a drastic decrease of *Cystoseira* and *Sargassum* species in historical sites of sub littoral zones; however, an extensive lack of information on the current presence, distribution and status of these engineering algal species in the area has also been pointed out.

In order to explain the long-term algal decline in historical sites and bridge the gap on the present occurrence and distribution of these algae in the Gulf, a new study has been carried out at different spatial scales. The percentage of coastal landscape transformation has been quantified at the gulf scale whilst at smaller geographical scale (Ischia Island) the introduction of different hard structures has been quantified. Finally, the current distribution of Fucales species has been recorded and mapped.

Material and Methods

Coastal transformation analysis

The coastal transformation of the Gulf of Naples has been evaluated by using ortho-photos selected from Google Earth™. In particular, transects 150m long were selected and plotted along the shoreline. For each transect, the percentage of natural/artificial coastal extension has been estimated and then related to the total coastal length. In order to find a relationship between the coastal transformation and the loss of algal diversity, the Gulf of Naples has been divided according to the same geographical sectors in which historical algal occurrence was reported (Table 1) (Buia et al., 2013).

Typologies and surface covered by new artificial hard structures

According to the different algal requirement for their settlement on hard substrates, the artificial structures recorded around the Ischia Island have been monitored and classified according to their origin: natural rocks and human-made buildings. In the first category natural blocks of different geological origin (granite, sandstone, volcanic) with various forms and slopes have been included. Emergent and submerged breakwaters (with different shape and orientation, connected or not with the shore line) are usually built overlapping these substrates. A second category has been created for human-made constructions, usually done of concrete, concrete with metal, concrete with rocks; tetrapod blocks, mixed concrete cubes, piles, and piers are examples of these hard substrates.

Surfaces covered by each hard artificial substrate (emergent breakwaters, submerged breakwaters, tetrapod blocks, mixed concrete cubes, concrete cast on rocks, piles and piers) were quantified and georeferenced in a GIS database. Different layers have been realized from a satellite image available from the plug-in Open Maps on qGIS 2.8.1-Wien. The total surface of the structures has been computed.

Current distribution of Fucales species

Cystoseira and *Sargassum* species have been extensively mapped within the shallowest fringe of Ischia: their occurrence has been acquired by snorkelling and kayaking surveys and digitalized in a GIS database (scale 1:2,500).

Results

Coastal transformation analysis

The analysis of the nature of the Gulf of Naples coastline pointed out a development of artificial constructions for 69,834m, representing about 34% of the total coastal length (Table 1).

Table 1: Sectors of the Gulf of Naples. (SCL=sector coastal length; N-TCSL=non-transformed coastal sector length; TSCL= transformed sector coastal length; %TL= percentage of TSCL on Total Length).

	Geographical sectors	SCL	N-TCSL	TSCL	% TL
Ischia	North	10,570	5,110	5,460	2.7
	East	6,895	5,405	1,490	0.7
	South	13,872	13,192	680	0.3
	West	7,160	5,085	2,075	1.0
Procida	North	2,850	1,920	930	0.5
	East	6,601	6,029	573	0.3
	South	3,300	2,738	563	0.3
	West	4,177	4,117	60	0.0
	Vivara	3,300	3,296	5	0.0
Pozzuoli Bay	Miseno West	6,000	3,803	2,168	1.1
	Miseno East	7,950	6,098	1,853	0.9
	Pozzuoli	8,250	3,645	4,605	2.3
	Pozzuoli East	9,150	2,468	6,713	3.3
Neaples Bay	Gaiola - Vico Equense	57,198	21,105	36,093	17.8
Sorrento Pen.	Vico E. - P.ta Campanella	29,161	24,832	4,329	2.1
Capri	Capri	26,788	25,746	1,043	0.5
	Total length (m)	**203,222**			**33.8%**

The loss of historical records of fucoids in the different sectors in which the area has been divided seems to correspond to the intensity of the development of artificial infrastructures (Fig. 1). In the bay of Naples, in front of the homonym city and its suburbs, more than half of the coast (63%) is artificial and the loss of species is as high as 78%. A comparable loss of species (67%) has been recorded in the Pozzuoli Bay (49% of coastal transformation), where a substantial industrial settlement has developed on the eastside.

Among the Phlegrean Islands, the northern side of Ischia has recorded a massive urbanization (52%) (Fig. 2) (Zucco, 2003), to which a total loss of fucoid species corresponds. As concerns the other sectors of Ischia and Capri, the lack of biological historical data does not allow to detect any other relationship with the low change of the coastal landscape.

Typologies and areas covered by new artificial hard structures

The dominant artificial structures around the coasts of Ischia island are represented by breakwaters (about 185,000 m^2) (Fig. 3). 49% of these artificial structures are emergent blocks, with various orientations and shore connections, and they are mainly located on the northern side of the island, in front of sandy beaches. They are also deployed on to the original rocky substrate, with no respect for the geological nature of the local reefs.

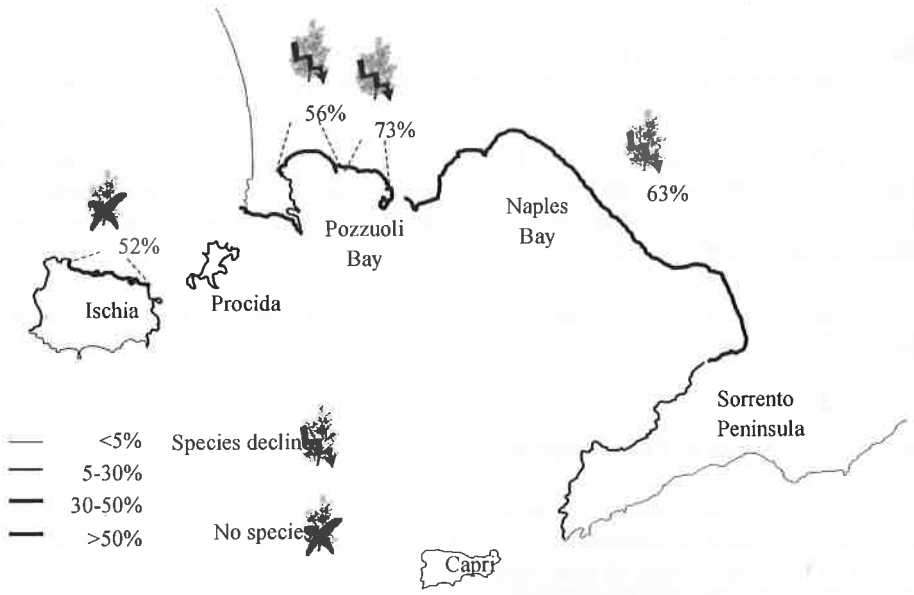

Fig. 1: Percentage of coastal transformations in different sectors of the Gulf of Naples in which historical records were reported and dramatic decline of fucoids were detected.

Fig. 2: Old (1920-1930, on the left) and current (2015, on the right) shoreline landscapes of three sites on the northern coast of the Ischia Island.

Submerged breakwaters (52,845m^2) only occur on sandy bottoms along the southern side of the island, in front of the Maronti beach, where they were deployed to reduce the local strong coastal erosion, which previous beach replenishment failed to mitigate (Gambi et al., 2005).

One third of the artificial buildings around the island, covering a surface of about 84,000 m^2, are constituted by concrete structures.

Current distribution of Fucales species

Results of the surveys all around the island of Ischia confirmed the loss of historical occurrence of shallow fucoid populations on the northern side of the island in relation to the deployment of new substrates and the loss of the natural habitat where these algae thrive (Fig. 4). Natural substrates still occur in the inner side of Punta Vico Bay, where just a relict spot of *Cystoseira compressa* and *Sargassum vulgare* exists. *Cystoseira* and *Sargassum* spp. are still present around the shallow coasts of the island althought an ongoing homogenization of diversity has been recorded at the island scale. *Cystoseira compressa* (the less sensitive species) is the more widespread species;

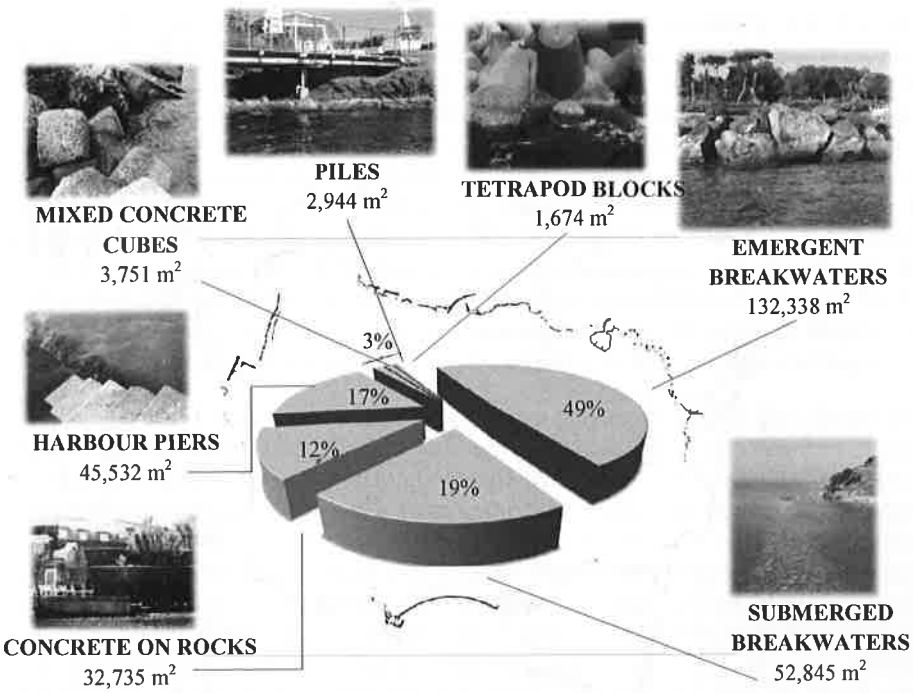

Fig. 3: The typologies of the artificial structures positioned around the Ischia Island and their covers.

fragmented stands of *Cystoseira amentacea* (the most sensitive) already exist while the highest diversity has been reached in rocky pools, an uncommon feature for the island, where also *S. vulgare* and *C. crinita* may occur.

In general, no fucoid records were found on artificial structures, generally providing vertical habitats. Opportunistic species (i.e. the mussel *Mytilus galloprovincialis*, the calcareous red alga *Corallina elongata*) have settled here and non-indigenous species (such as the red alga *Asparagopsis taxiformis*, the calcareous sponge *Paraleucilla magna* and the bryozoan *Zoobotryon verticillatum*), some of them with an invasive pattern, have been recorded. Very few spots of fucoids have been found only on more than 30-year-old infrastructures (both natural and man-made) but only where the slope is very gentle and the artificial structures are close to the natural algal population.

Conclusions

Hard artificial structures have become ubiquitous features of coastal landscapes as a result of the increasing human development in maritime areas and to prevent the coastal erosion. In the Gulf of Naples the percentage of coastal transformation is now a third of its coastline (34%), approaching very quickly to 50%. The extent of the problem of beach erosion is alarming, especially around the Ischia island. Comparing the extension of its beaches between the sixties and 1999, a loss of 65% of sandy shore

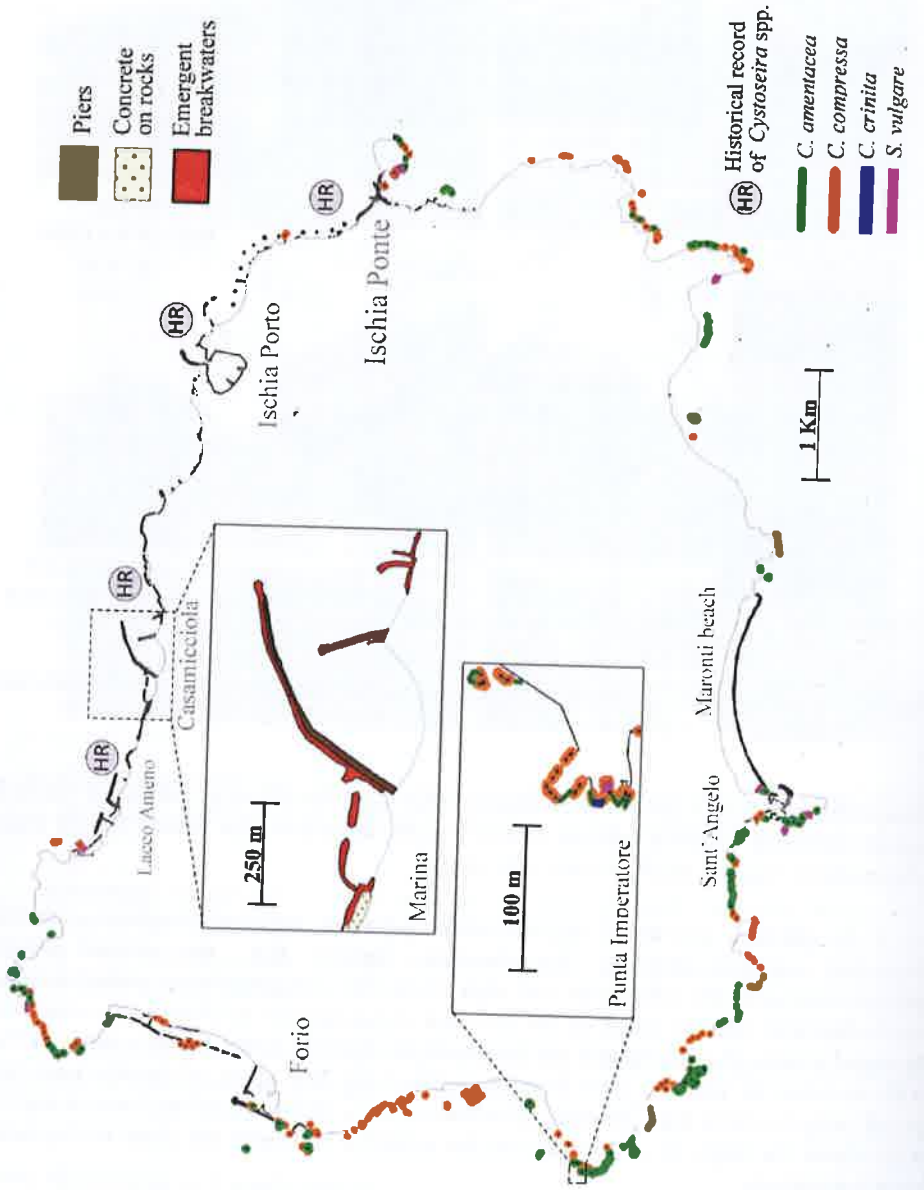

Fig. 4: Up-to-date mapping of upper sub tidal fucoid populations around the Ischia Island and the occurrence of hard artificial structures.

is evident (Zucco, 2003). However, the attention on the impacts that artificial structures may have on the marine native ecosystems is very poor (Chapman and Bulleri, 2003; Airoldi et al., 2005; Bulleri & Chapman, 2010).

Besides the marinas, emerged and submerged breakwaters are the most widespread hard structures built up along the Neapolitan coasts. Unfortunately, it seems that the nature of the rocks that have to be introduced in the sea is not taken into account. In this way the new substrates can be different from the natural reefs present in the area. Our data on the occurrence of important engineering species such as *Cystoseira* and *Sargassum* seem to testify that they are not able to colonize every kind of substrates but prefer blocks with gentle slopes and non-smooth walls. On the opposite, opportunistic and non-indigenous species seem to be favoured. Furthermore, these structures can be deployed close to sedimentary bottoms and the severe sand-scouring may prevent fucoids settlement. In addition, breakwaters, being not fixed to the seafloor, can be considered "motile environments" as they can undergo frequent and severe disturbances during storms, affecting the stability of the settled assemblages.

Along the coasts of Ischia ongoing homogenization of fucales diversity is evident in the upper sub tidal fringe. *Cystoseira compressa* (the less sensitive species, with highest zygote dispersal potential) (Mangialajo et al., 2012) is the widespread species and frequently colonize the habitat in the form of discontinuous patches. Stands of *Cystoseira amentacea* (the most sensitive species, with a very low estimated dispersal potential, due to the large size of eggs and the lack of buoyancy) still exist: they are more continuous but limited. The settlement on artificial substrates, as already reported by Susini (2006) can be possible but it seems mainly related to the distance of fertile populations on nearby natural substrates and to the time of hard structure deployment (in our case more than 30 yrs), where opportunistic species could create favourable conditions for their settlement.

Their distribution and abundance is favoured by substrates characterized by gentle slopes and never occurs on vertical and smooth rocks. These latter conditions do not occur in rocky pools that, even if they are an uncommon habitat on the island, host the highest fucoid diversity. *Sargassum vulgare* seems to be the species with the highest dispersal potential: the presence of air-bladders allow floating over large distances, better overcoming the habitat fragmentation caused by the introduction of new habitats.

These results seem to confirm a spatial correspondence between habitat loss and coastal transformation. However, additional environmental changes, unfortunately always anthropogenic, can be invoked to explain the decline of these sensitive algal species. Certainly, in coastal management there is an evident lack of planning and a strong fragmentation of skills and responsibilities (Country, Regions, and local authorities). A stronger collaboration between engineers, managers and ecologists for a better planning and management of coastal zones, in order to mitigate the impacts of continuous coastal landscape transformations and to preserve biodiversity (Airoldi et al., 2005, Moschella et al., 2005, Firth et al., 2013), has to be pursued.

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