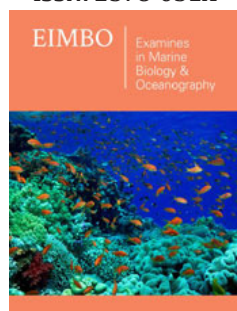


The Sediments of *Posidonia oceanica* Meadows as Strengthening Lands Against Coastal Erosion along Italian Coastline

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Abstract

Italian coastal regions are heavily urbanized and, actually, exposed to a marked risk of coastal erosion. To control and counteract this negative trend the submerged meadows of *Posidonia oceanica* species could play an important functional role limiting sea swells and wave motions for the protection of national coastline from erosive processes. In this way, at the base of the meadows, there are sedimentary textures, made of intertwined rhizomes, roots and sediments, named “mattes”, representing a special kind of strengthening lands able to oppose against hydrodynamic forces. This study was conducted on a submerged beach of Cavo bay, in Elba island (North-Western Italy). The experimental trial showed the functional effect of the “matte” against coastal erosion based on the high resistance of the whole root system of *Posidonia* meadow able to compact mobile substrata as a reinforced soil in coastal seawaters. In conclusion, *Posidonia* “mattes” are very important to stabilize littoral seabeds for the protection of Italian sandy beaches against coastal erosion.

Keywords: Italian coastline; Coastal erosion; Elba island; *Posidonia oceanica* “matte”; Shear resistance

Introduction

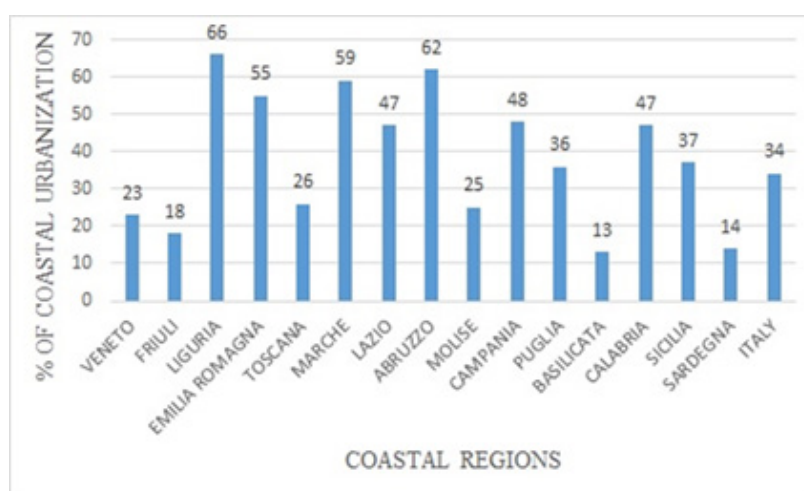


Figure 1: Percentages of coastal urbanization in Italian coastal regions.

Italian coastal regions are overcrowded by people and human infrastructures. In fact, about 30% of Italian population, as 16.9 million inhabitants, lives in littoral areas within

a narrow coastal belt that represents only the 13% of the whole national territory [1]. Along Italian coastline, 2.056Km², as the 34% of the whole coastal boundary, have been heavily urbanized, as reported in Figure 1, where the percentage values of urbanized surfaces are represented at regional levels (Figure 1).

Indeed, the overcrowding and the rough urban development in seaboard areas have been occurred without any kind of landscape planning, so producing conditions of environmental decay in coastal landscape. This kind of confused overbuilding has caused a marked reduction in the sedimentary transport towards coastline leading to a poor nourishment of littoral regions. Italian coastal regions are historically exposed to geological and morphological instability leading to a marked littoral withdrawal. This condition of coastal decay is originated not only from natural processes, as wave motions, tides and currents but also, and above all, from human pressures strictly connected to a heavy urbanization of coastal regions and

to an increasing concentration of socio-economic activities close to Italian coastline. As a result, it has been occurred, in time, the gradual imbalance of an unstable geomorphological equilibrium along the national coastline and it has been marked the risk of coastal erosion [2]. A late report, released by ISPRA [3] highlights that 841Km of Italian coastlines are in erosion, as the 17.9% of sandy beaches (Figure 2). However, between 2007 and 2019, it has been recorded a slight tendency towards a better stability of the national coastline. This changing trend is the possible effect of all the legislative efforts spent by Italian and Regional authorities to counteract the unstable equilibrium of Italian seaboard areas. At a regional level, the present pattern is quite different because there are some regions, such as Sardegna, Basilicata, Puglia, Lazio and Campania where the regional coastlines, actually in erosion, are longer than the ones in advancing, while the littoral regions with the highest values of coastal erosion are Calabria, Sicilia, Sardegna and Puglia (Figure 2).

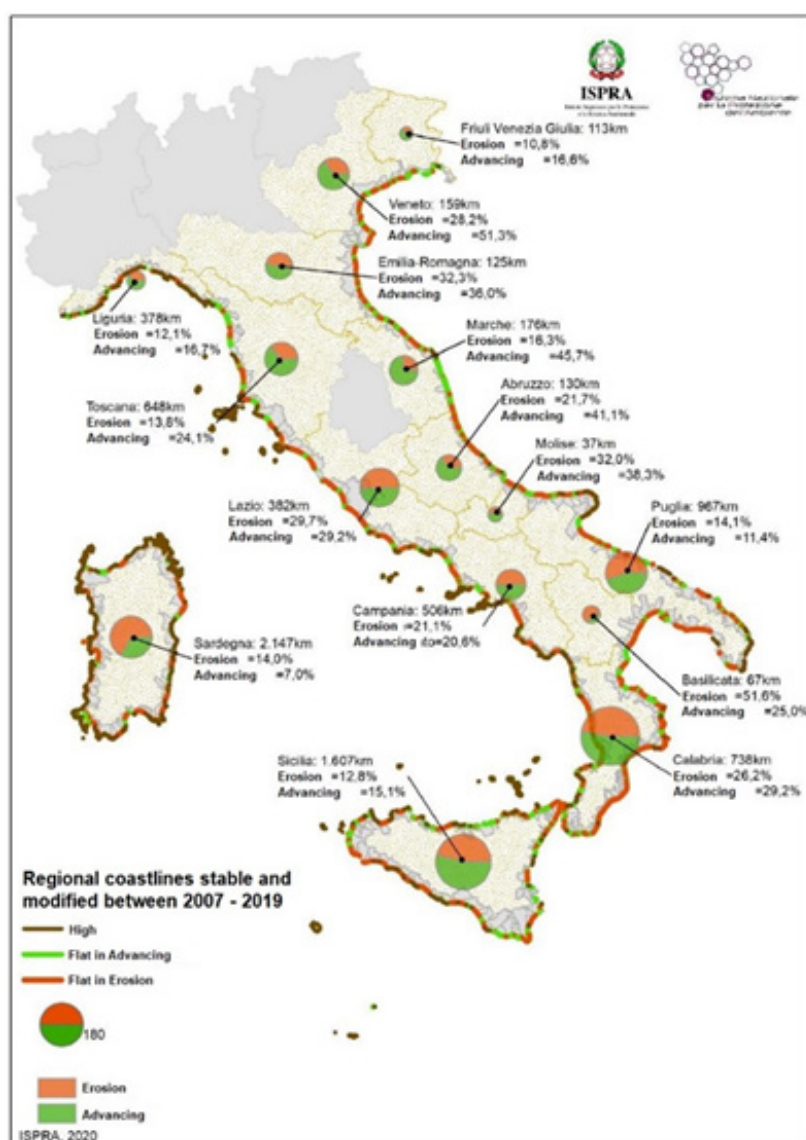


Figure 2: Regional coastlines of Italian seaboard areas in erosive and advanced trends in the period 2007-2019.

To limit this growing environmental risk, the marine plant *Posidonia oceanica* (Linnaeus) Delile could play an important ecological and functional role. This marine phanerogam, representing one of the most important endemic species of the Mediterranean Sea, can form in good and pristine ecological conditions, extensive meadows on its infralittoral bottoms, so representing the typical “climax” ecosystem of the basin [4]. In this way, *Posidonia* beds have been protected by European laws through the Habitat Directive 92/43/UE, defined like “Priority Habitat” and classified as “Best Concern” by the International Union for Conservation of Nature (IUCN) [5]. Amongst the main functions performed by the meadows, *Posidonia* leaves and the basal sediments of the meadows, organized in a typical formation called “matte”, can limit the hydrodynamic energy, caused by sea swells and tidal currents, so reducing the effects of coastal erosion. As a result, *Posidonia* meadows can be considered an important tool not only for the protection of coastline from erosion processes but also for a steady and dynamic equilibrium of littoral regions. In this paper, it has been tested the relationships between the sedimentary features of the “matte” and the technical properties shown by the radical system of the plants, to ensure a better stability of infralittoral bottoms, so limiting the risk of coastal erosion [6].

Phylogenesis and biotechnical capabilities of the plants

There is a common origin in plant evolution on Earth. This long phylogenetic history began 430 million years ago during

the Paleozoic Era. In that geologic period, it happened a great diversification, of plant kingdom and appeared the first terrestrial Angiosperms. Amongst them, it came out an ancient *Posidonia* genus, terrestrial ancestor of the actual *Posidonia* marine species. A long time after, in the middle of Cretaceous period, about 100 million years ago, terrestrial Angiosperms began to return into the sea. During this long time, some species of Angiosperms lived in fresh and brakish waters, gradually adapting to marine life [7-10]. Amongst these, *Posidonia* cretacea Hosius Von der Mark, today extinct, was the putative ancestor of the present *Posidonia oceanica* species that established, during the Paleocene era, about 60 million years ago, in the Mediterranean Sea. So, there is a tight connection between terrestrial and marine Angiosperms, highlighted, also, in their root systems able to conduct some important functions as are:

- Great capacity of resistance against mechanical stress especially marked on grounds subjected to landslides;
- High capacity to strengthen the soil through the root systems of the plants;
- Suitable resistance against pulls, shear and tractions by the roots of the plants [11].

Plant species, characterized by high biotechnical abilities, have a marked reinforced action on terrestrial lands depending on the shape of the roots, on their density and, therefore, on the whole radical mass (Figure 3).

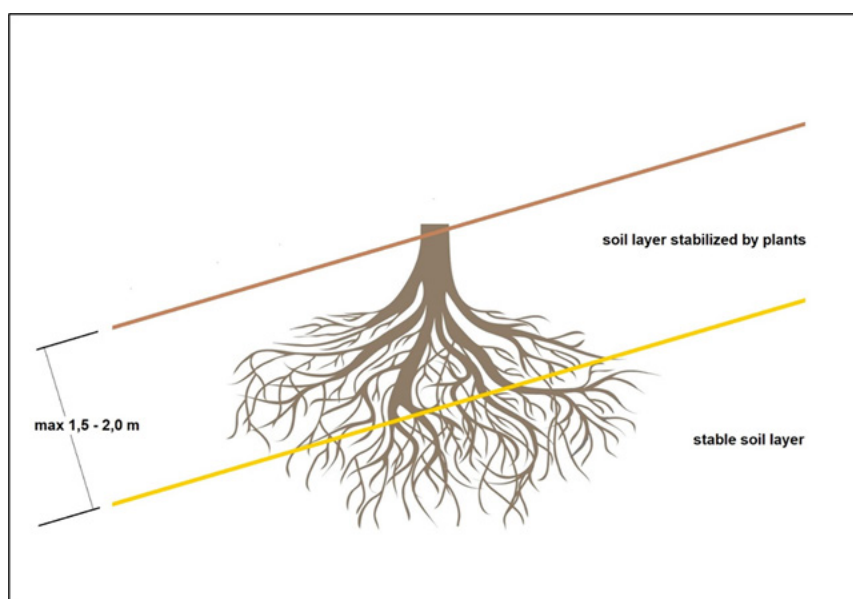


Figure 3: Pattern of reinforcing effects through the root systems of terrestrial plants.

By the field experiences conducted in Austrian regions between 1950 and 1980 about the connections on plant eradication [12], result some important principles:

- Amongst the pioneer plants, according to their radical shapes, it is possible to distinguish those at extensive rooting as *Salix* genus with large and deep roots, those at intensive radication, as Gramineae with dense and superficial roots

and those at mixed rooting.

- The radical whorls located at different strata in the ground compact the soil much better than those located at a single stratum.
- The volume of the whole root systems is related with the volume of aerial parts of the plants.

d. The plants, characterized by high levels of resistance not only against the risk of silting up but also against erosive processes, are good soil binding because these plants have high active resistance due to a deep root system very elastic and resistant to pulling actions.

e. The shape and the volume of the roots, according to the location of the plant, are subjected to variations connected to the levels of humidity and to the trophic content of the soil.

Also, marine phanerogams, terrestrial Angiosperms fully adapted to marine environments, are characterized by the same principles. In particular, the sediments of the “mattes” intertwined with the rhizomes of *Posidonia oceanica*, represent a kind of strengthened land able to oppose against wave motions and marine currents [6]. So, *Posidonia* beds could carry out, in the coastal marine environment of Mediterranean Sea, the same cohesive role that terrestrial plants, through their roots, perform on continental lands. In this paper, it has been inquired the biotechnical properties of the root system of *Posidonia oceanica* and, more generally of the whole “matte” against cuttings, tractions and hydrodynamic forces.

The sediments of *Posidonia oceanica* meadows

The sedimentary texture of *Posidonia oceanica* meadows is formed by inorganic and biogenic materials captured through the filtering action of *Posidonia* leaves over seawater dynamics [13]. This slow and continuous process of sediment accumulation leads, in time, to the vertical growing of the meadows because the deposition of detrital particles is coupled with an upward growth of orthotropic rhizomes. The result of this process is the formation

of a terraced structure made of intertwined rhizomes, roots and sediments, causing a gradual rising of bottom depths [14,15]. This special formation is nicknamed by scientific community “matte” reaching, in time, a thickness of several meters until hydrodynamic effects, caused by sea swell, hampers the further growth of the *Posidonia* beds. In such dynamic and balanced equilibrium, the meadows show a regular mode, forming a continuous vegetated belt located between the shoreface, made by terrigenous loose sediments, and offshore shelf materials [16,17]. This typical vegetated barrier, close to the coastline, as a fringing reef, can protect sandy beaches from erosion processes. At the base of the meadows, the sediments, forming *Posidonia* “mattes”, are characterized by three different depositional areas, as are:

- A surface area closed to the upper limits of the meadows. These sediments, representing the passage towards coastal system, are enriched by organic fragments originating from the meadows.
- A central area located in the middle of the meadows. The sediments at the centre of the meadows are fine-grained particles with an important organic component and a substantial sieve fraction.
- A deep area close to the lower limit of the meadows. These sediments are located between the meadows and some coastal biocenosis, as for instance, coralligenous [16]. Therefore, these structures are affected by the presence of wreck sediments originating from continental shelf. So, the lower “matte” is characterized by a complex and rough granular texture, enriched by an important organic fraction.

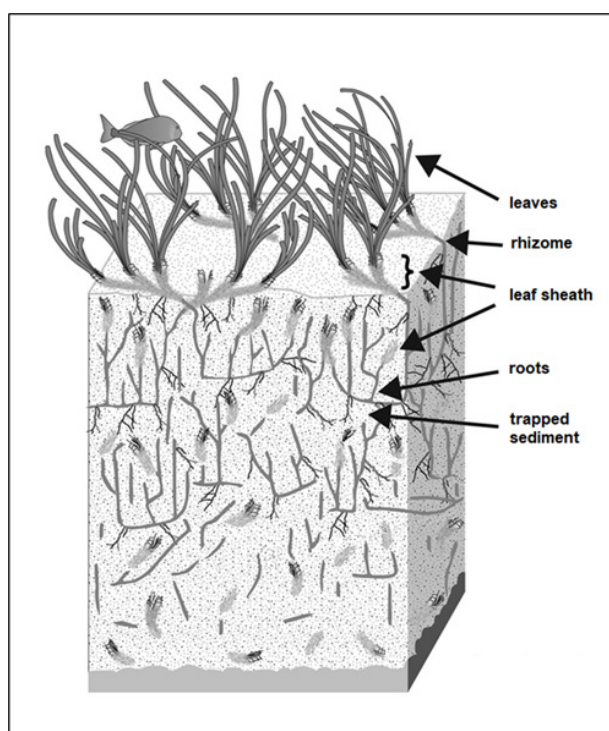


Figure 4: Section of a *Posidonia oceanica* ecosystem.

So, the structure of *Posidonia oceanica* ecosystems is composed by lower stratocenoses made by rhizomes and root systems and upper stratocenoses made by the leaves of the plants (Figure 4). This pattern is subjected to intense and continuous hydrodynamic forces leading to loss and replacement of these basic elements. In conditions of dynamic equilibrium this system can last thousand years, so representing the typical “climax” ecosystem of the basin. In general, the lower section of this complex texture, organized in a deep “matte”, is stronger than the upper strata because the root system is enriched by tannic cells and lignin compounds able to slow down decay processes [12].

Study Area

The island of Elba is one of the seven islands forming the National Park of Tuscan Archipelago including also several islets located in the Northern Tyrrhenian Sea just in the middle of the

Pelagos Sanctuary established in 1999 as Marine Protected Area (AMP). Elba island is the third Italian island for its extension, as 22.350ha and it is about 10km from Italian coastline (Figure 5). The Island shows a dimly triangular shape, but it appears extremely irregular in its coastline characterized by a lot of gulfs and headlands indenting the island contour. The coastal regions are mainly represented by underwater and surfaced beaches extended inside gulfs, bays and little inlets. The materials forming the sandy coastline of the island change their granulometry from simple sands, to gravels but are lacking thinner fractions, as silt and clay. The submerged beaches of Cavo bay, selected as study area (Figure 6) and deriving from “Cavo Formation” [18], are formed by fine sands and little white pebbles mainly formed by variegated clayey schists, often silty and rarely marly, with typical plate fracture filled by a dense network of quartz, and veins visibly deformed.

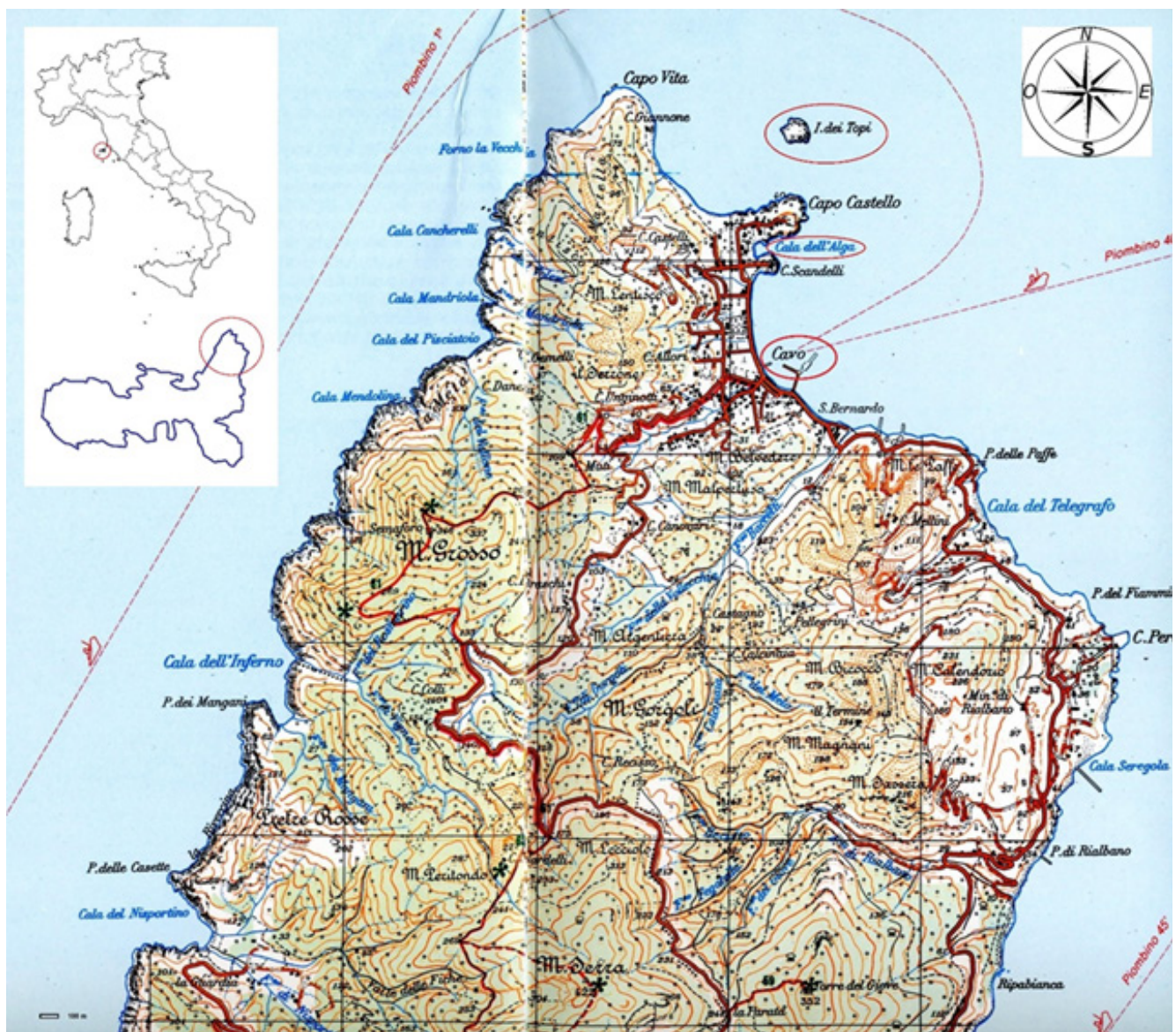


Figure 5: Geographic map of Elba Island, North-Eastern area (IGM 1:25000).



Figure 6: Cavo bay in Elba Island.

Materials and Methods

This study began through a detailed experimentation conducted by the Biological Department of Pisa University (Pisa, Italy) in partnership with the Italian Association for Soil Bioengineering (AIPIN) and with Maccaferri S.p.A., to test new kind of afforestation applied to some meadows of *Posidonia oceanica* meadows in a regression trend [19]. The field survey has been conducted on *Posidonia* beds located in the bay of Cavo, close to the coastal village of Rio Marina, along the north-eastern coast of Elba Island (Tuscany, Italy), using an especial steamboat released by Cavo Diving Centre

(Figure 7). In this way, samples of sediments, as sands, dead “mattes” and living “mattes” have been collected so to detect the biotechnical abilities of the plants in stabilizing coastal depths against wave motions and hydrodynamic forces [12]. The tests, at direct shear and pressure, have been realized with a specific device in the technical laboratory of Geoplanning S.p.A. (Figure 8). The experiments have been performed on three samples for each kind of sediments (sands, sands+dead “mattes”, sands+living “mattes”). The plots, by dimensions of cm 6x6x2, have been subjected to three different vertical loadings, as 49kPa, 98kPa and 147kPa, at the same timing (24h) and deformation speed (0.03mm/min) (Figure 9).



Figure 7: Steamboat used for field surveys [19].

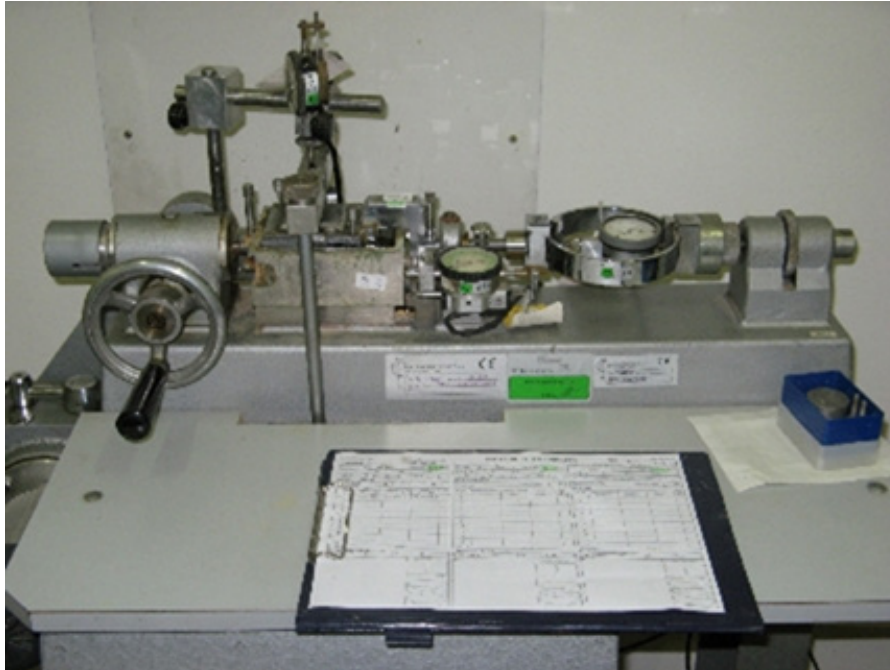


Figure 8: Device “Casagrande” used for shearing tests.



Figure 9: Plot of a living “matte” ready for laboratory tests.

Result and Discussions

The analysis of sediments pointed out the homogeneous structure of the “matte” characterized by a medium-fine texture. The grains are quite thin with diameters (ϕ) between 0.1 and 0.4mm. The composition of the sands is mainly quartz with traces of hematite and limonite coming from a continental and illegal outflow of mine debris. The experimental tests, realized in drained conditions, showed through some factors, as cohesion (c) and

friction angle (ϕ), the marked increase of substrata resistance against shear by rhizomes and root systems of *Posidonia oceanica* species (Figure 10). In fact, the cohesive strength (c) of the “matte” grows respectively from 0.0kPa for simple sands to 22.0kPa for sands+dead “matte” until 24.0kPa for sands+living “matte”. Also, the resistance of “matte” against shear (t) and pressure (p) grows from 130kPa for simple sediments to more than 160kPa for sands +living “matte” (Figure 11).

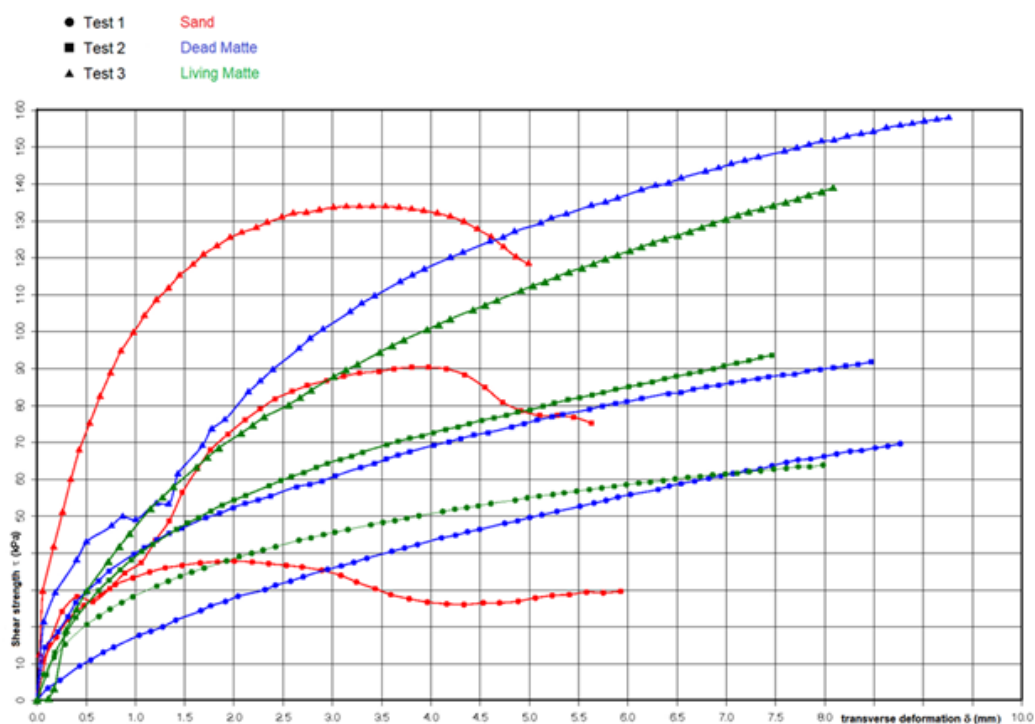


Figure 10: Curves of correlation concerning shear resistance t (kPa) and transversal deformation d (mm) for the three examined tests.

INTERPRETATION OF THE DIRECT SHEAR TEST (CD)

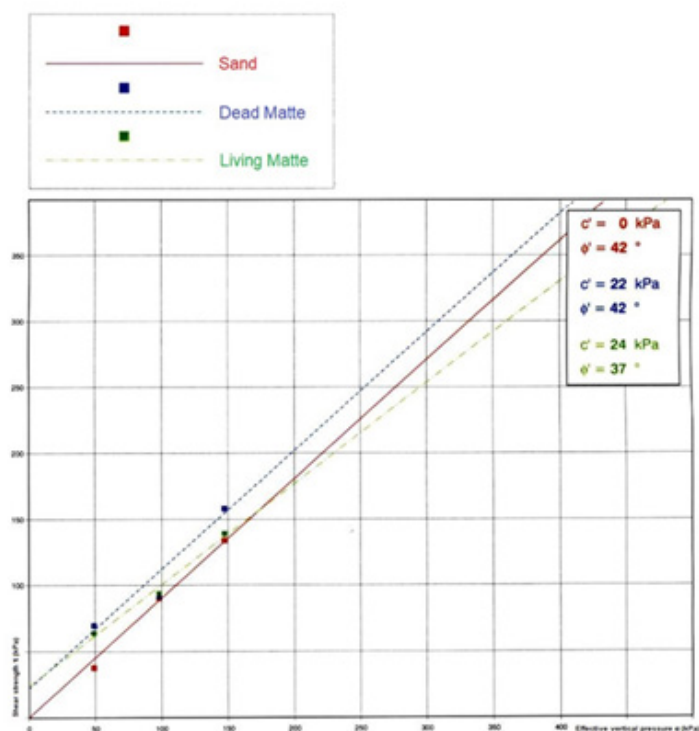


Figure 11: Resistance of different kind of substrata subjected to direct shear and pressure.

The trial to value the resistance of the “matte” against direct shear has been realized using a “Casagrande” device, formed by two square frames overlapping and flowing each other. The samples are inserted in the frames and are subjected to compression effort (N) and to horizontal stress (T). Known N, T and the section of the sample, it is possible to calculate the correspondent values of Coulomb line as $P=N/A$ and $t=T/A$. Just repeating the same test for different samples, it is possible to obtain the shear value (t). The trial has been conducted at controlled deformation speed measuring with a dynamometer the value of horizontal effort with the rise of deformation. So, it is possible to design the graph t-def at the different values of breaking and, finally, to draw the following formula: $t=c+ptg\phi$ [20]. From the experimental trial conducted in laboratory, it is clear that the root resistance of *Posidonia oceanica* is more evident as far as the roots of the plants are buried in the substrata. The reinforced effect of the “matte” is based not only on the high resistance of the roots, but also on the several branches of the whole root system that, with its rhizomes, extends deeply and in all the dimensions of coastal depth [12].

Conclusions

The research highlights the important function of *Posidonia oceanica* meadows to stabilize marine depths through the root system of the plants able to compact and reinforce mobile substrata, acting as a “reinforced soil”. In this way, *Posidonia* “mattes” show a great resistance against share and pressure by hydrodynamic forces, being very important to stabilise the seabed of shallow seawaters for the protection of littorals against coastal erosion. So, it becomes very important to protect *Posidonia* beds against all the threats that are actually reducing their extension in the Mediterranean Sea. In these conditions, Italian sandy beaches are actually exposed to a growing coastal erosion for the absence of a natural littoral reef formed, a long time ago, by *Posidonia oceanica* meadows. Also, the dead “mattes” keep an important role against erosive processes and could become ideal places to realize a potential afforestation of coastal depths through transplantation methods widely experimented.

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